Understanding the neurocognitive mechanisms of sports performance under pressure through cognitive training

Understanding The Neurocognitive Mechanisms of Sports Performance Under Pressure Through Cognitive Training

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ABSTRACT

Accumulating research has emphasised that anxiety can profoundly interfere with task performance during sporting competitive contexts. Recent research has implicated disruptions to attentional control in explaining such impairments. The present PhD thesis intended to build upon recent advances in sports science and cognitive affective neuroscience, by marrying theoretical predictions from the Attentional Control Theory (ACT; Eysenck, Derakshan, Santos & Calvo, 2007) with recent developments in cognitive training, to develop lab based training interventions, to improve attentional focus and performance in lab-based and field-based sporting tasks performed under pressure. In doing so, another critical aim of the thesis was to identify potential neurocognitive mechanisms by which the experience of pressure related anxiety in sporting contexts can lead to impairments in motor performance.

In Chapter 2, a sample of tennis players undertook training on a novel visual search training task designed to enhance inhibitory control. Transfer effects of training were observed on a lab index of inhibition, tennis performance and gaze behaviours reflecting attentional control in tennis. Results of Chapter 3 in turn revealed that training on a an adaptive working memory training task, resulted in transfer effects on indices of WMC, tennis performance and gaze behaviours. In Chapter 4 an 5 the emphasis was placed on the potential impact of attentional biases on performance under pressure. In Chapter 4, tennis players undertook an Attentional Bias Modification training intervention and results indicated that the intervention elicited significant changes in attentional bias with transfer effects of

training also being observed on tennis performance. Finally, in Chapter 5, a study was conducted to explore whether neural markers of cognitive effort and error monitoring would modulate the attentional bias-performance relationship in a sample of experienced tennis players. Result indicated that the relationship between levels of attentional biases and tennis performance was modulated by the N2 as measured on a flanker task. Performance was also associated with participants' levels of attentional biases which was in turn modulated by their gaze behaviours during the tennis task performed under pressure.

Overall, findings from this PhD thesis suggest that it is possible to target specific cognitive mechanisms such as attentional control and attentional biases, using lab based interventions, to enable athletes to cope with the negative impact of competitive pressure on motor performance. Moreover, the current findings provide novel insight into the potential neurocognitive mechanisms that modulate how sports performers respond to competitive pressure.

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Chapter 1

General Introduction

1.1 Chapter Overview

The principal aim of this chapter is to provide a critical review of previous research that has investigated the negative impact of anxiety on both cognitive and sports performance. In doing so, the present chapter will first outline the nature of anxiety and how this emotional state can negatively impact sports performers. In addition, this chapter will review theoretical propositions that have linked impairments in attentional control to the experience of anxiety in both the general population and in sports performers. This chapter will then emphasise how the field of sports science has elaborated methods designed to investigate gaze behaviours as indices attentional control in sports which in turn contributed to the development of gaze based training intervention to protect athletes against the negative effect of anxiety when taking part in competitive activities. This chapter will also discuss recent findings in the area of cognitive training that have demonstrated the potential of employing such methods in enhancing attentional control in normal and emotionally vulnerable populations. Finally, the main aims and an outline of the thesis will be presented. The chapter will end by highlighting methodological issues relating to the recording and the analysis of gaze behaviours in sports settings.

1.2 Sports Performance and Competitive Pressure

Effective performance in sports is characteristically evaluated in terms of athletes' technical, tactical or physical abilities. However, an essential index of successful performance directly relates to the ability to perform at optimum levels of performance when confronted with high levels of pressure in anxiety provoking situations which are frequently encountered in competitive sporting contexts (Wilson, 2012; Eysenck & Wilson 2016). This is especially relevant in sporting disciplines which require optimum level of focus and attention and where performers are required to execute complex motor skills under pressure such as tennis, golf, archery or shooting. Recent advances in the area of sports psychology have shown that elevated levels of anxiety, commonly characterised by the presence of worrisome thoughts, are generally associated with the ego-threatening nature of taking part in competitive activities, where one's performance is often evaluated by peers, coaches or members of the public (Janelle, 2002; Wilson, 2012; Oudejans et al., 2011). Furthermore, an inability to maintain high levels of performance when confronted with heightened levels of stress can affect both expert and recreational athletes alike (Lavallee, Kremer, Moran & Williams, 2012). Experiencing high levels of anxiety in sporting contexts can be so debilitating that it often results in 'choking' which refers to a significant deterioration of performance, despite one's skill level and irrespective of incentives for superior performance (Baumeister, 1984). Specifically, choking frequently results in a partial or total breakdown in motor performance and negative competitive outcomes (Baumeister, 1984; Messago, Harvey & Janelle, 2011).

When taking part in competitive sporting activities, the ability to sustain optimal performance under high levels of competitive pressure is often what differentiates performance attainment from perceived failure (Jones, 1991). A large body of research in the area of cognitive neuroscience and sports psychology has emphasised the link between anxiety and performance impairments in both cognitive and sporting tasks through the detrimental impact that anxiety can exert on attentional control (Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan & Eysenck, 2009; Eysenck & Wilson, 2016, Nieuwenhuys & Oudejans, 2012, Nieuwenhuys & Oudejans, 2017).

1.3. Anxiety Definition, Anxiety in Sports

1.3.1 Definition of Anxiety

According to the DSM-5, anxiety is a negative affective or motivational state that generally occurs when an individuals' levels of perceived threat are elevated or if a current goal appears to be obstructed by potential threats. Anxiety is generally observed as a personality trait or as an emotional state which manifests itself in the form of behavioural, psychological and physiological changes (Eysenck and Calvo, 1992). More specifically, individuals experiencing elevated levels of anxiety often engage in narrowed forms of thinking, mainly converging towards worrying or negative thoughts whilst often displaying signs of restlessness, nervousness or agitation as well as elevated blood pressure and increased heart rate. Power and Dalgleish (1997; pp. 206–207) defined anxiety as "a state in which an individual is unable to instigate a clear pattern of behaviour to remove or alter the event/object/interpretation that is threatening an existing goal." Eysenck and Derakshan (2009) in turn explained that as a result, anxious individuals tend to implement diverse strategies that are directed at reducing potential threats obstructing current goals. Such strategies are thought to generally lead to a reduction of cognitive resources and increased distractibility which can severely impact cognitive functioning and more specifically, cognitive processes relating to the efficient allocation of attentional focus in goal directed tasks (Derakshan & Eysenck, 2009). Finally, anxiety can also be expressed in different ways. For example, Spielberger (1983) initially made a distinction between state and trait anxiety. Specifically, Spielberger (1983) defined state anxiety as being an unpleasant emotional response occurring while encountering or coping with unpleasant threatening or dangerous situations. In contrast, trait anxiety is believed to reflect the existence of stable individual differences in the tendency to respond with state anxiety in the anticipation of threatening situations.

1.3.2 Anxiety in Sports

In sports, competitive anxiety, a form of state anxiety experienced in pressurised settings, represents a negative emotional reaction to competitive stressors (Mellalieu, Hanton, & Fletcher, 2009). This type of anxiety tends to be so pervasive in competitive contexts that researchers in this area have concluded that it is often the ability to handle sports-related anxiety that makes the difference between winning and losing (e.g. Jones, 1991). The detrimental effects of anxiety on sport performance (Mellalieu et al., 2009), are thought to mostly result from physiological and cognitive changes that are associated with the experience of anxiety. Precisely, physiological changes are characterised by reported levels of "somatic" anxiety, which refers to the objective symptoms of physiological arousal, as well as the subjective perceptions of physiological arousal. "Cognitive" anxiety, on the other hand, refers to the presence of anxiety in the form of worrisome thoughts, negative expectations and self-doubts. Cognitive anxiety is thought to exert the greatest negative impact on overall sport performance (Martens, Robins, & Damon, 1990; Vickers & Williams, 2007, Oudejans et al,. 2011).

A large amount of research emanating from field of sports psychology has attributed anxiety related performance breakdowns and ‘choking’ to the disruptive influence of self-focused attention on the performance of previously learned motor skills (i.e. disrupted automaticity) when pressure is elevated (e.g. Baumeister, 1984; Beilock & Carr, 2001; Masters, 1992). Nevertheless, as with previous research in cognitive and affective neuroscience mentioned earlier (Derakshan & Eysenck , 2009), a large body of research in sports has recently emphasised that the detrimental impact of anxiety on sport performance directly results from impairments in attentional control and processing efficiency (see Wilson, 2008, Eysenck & Wilson 2016). For example, Nieuwenhuys & Oudejans (2012, 2017) initially proposed integrated model which took into account anxiety related impairments in attention control when performing under pressure. Specifically, this model was designed to distinguish between positive and negative effects of anxiety and incorporated three operational levels (attentional, interpretational, and behavioural) at which anxiety may affect different aspects of goal-directed action in sporting contexts.

1.4 The Attention Control Theory of Anxiety

1.4.1 What is Attentional Control?

Attentional control represents the ability to adjust the allocation of attentional resources according to situational demands (Derryberry & Reed, 2002).

Furthermore, according to Shipstead Redick, Randall and Engle (2012), attentional control relates to the ability to efficiently direct attention toward goal-relevant information and away from distractive stimuli. Recent models of working memory (e.g. Miyake et al., 2000; Unsworth, Redick, Spillers, & Brewer, 2012) in turn propose that attention control reflect the efficiency of the main functions of the central executive of working memory in attaining a task goal.

According to Corbetta & Shulman, (2002) attention can be controlled in two specific ways. First of all, attention can be controlled in a top-down fashion, via a goal-driven attentional system, which is largely influenced by goals, expectations and knowledge. On the other hand, attention can also be controlled in a bottom-up manner, via a stimulus-driven attentional system, which is believed to be responsive to salient external stimuli (Corbetta & Shulman, 2002). These two distinct attentional systems are believed to work in synchronous ways.

1.4.2 Anxiety, Attention Control and Executive Functioning

It has been vastly suggested that besides the negative affective connotations which are its defining hallmark, anxiety is generally associated with deficient cognitive functioning, and especially the cognitive processes that are related to attentional control. The principal assumption of ACT (Eysenck et al., 2007) posits that anxiety is generally associated with substantial cognitive impairments such as the ability to apply sufficient levels of attention in goal directed behaviours. Specifically, ACT denotes that anxiety tends to promote stimulus-driven attentional processes to enable efficient threat detection at the expense of the goal-driven system needed to achieve task goals. Such imbalance between these two attentional systems as for effect to compromise the efficient allocation of attentional control resulting in undesirable outcomes such as increased distractibility and an inability to inhibit automatic responses, which, in turn, can lead to an increased sensitivity to internal distractors in the form worries as well as external distractors. Another negative repercussion of anxiety on attentional control, is that it can also result in impairments relating to the ability to switch attentional resources between tasks sets (Eysenck et al., 2007; Derakshan & Eysenck, 2009).

Consequently, the principal assumption of ACT denotes that anxiety tends to impair attentional control by mainly affecting the inhibition and shifting functions of working memory which greatly depend on attentional control. Inhibition refers to the ability to prevent inappropriate automatic tendencies from interfering with current incompatible goals or actions, whereas the shifting function reflects the ability to switch attentional focus between tasks in accordance with situational demands (Eysenck & Derakshan, 2011). According to ACT, disruptions to the switching function are thought to impair the ability to efficiently switch focus of attention from one task to another, whilst deficits in inhibitory control tend to cause attentional resources to be redistributed to task-irrelevant stimuli, such as worrisome thoughts about performance.

The field of cognitive and affective neuroscience has provided evidence to support the idea that anxiety can impair the efficiency of the different executive functions of WM. For example, using the antisaccade task, thought to represent a robust measure of inhibition, Derakshan, Ansari, Hansard, Shoker and Eysenck (2009a) found that when compared to low trait anxious individuals, high trait-anxious participants were generally slower to initiate an eye-movement away from an abrupt peripheral target. High anxious individuals were however no slower on prosaccade trials (i.e. orienting gaze towards a target) which does not require the involvement of inhibitory control (Derakshan et al., 2009a). Anxiety related impairments in inhibitory control were also confirmed using electrophysiological recordings. Specifically, Ansari and Derakshan (2011a) observed that individuals high in trait anxiety generally displayed lower fronto-central negativity in the period occurring prior to the onset of the to be inhibited target in the antisaccade task. This in turn explained the increased antisaccade eye-movement latencies observed in those high-anxious individuals. Functional neuro imaging (fMRI) studies have also shown that dorsolateral prefrontal cortex (DLPFC) activity is associated with the engagement of active inhibition to irrelevant information (Botvinick, Braver, Barch, Carter & Cohen, 2001). Bishop (2009) in turn reported that high trait anxious individuals generally displayed reduced activity in the DLPFC when undertaking a flanker task which required participants to ignore competing letter distractors when making a response. Thus, anxiety was believed to be associated with a reduced ability to successfully inhibit task-irrelevant material. The negative impact of anxiety on inhibitory control has also been observed when looking at state anxiety. For example, Booth and Pecker (2017) explored the impact of state anxiety on inhibition using a Stroop task and showed that participants who displayed elevated levels of state-anxiety, tended to display greater Stroop interference on incongruent trials which followed control trials. In another study, Moser, Moran and Leber (2015) demonstrated that distraction by salient and non-emotional stimuli could result in increases in state anxiety levels, providing support for a direct association between state anxiety and impairments in inhibitory control.

In terms of anxiety related impairments to the switching function, several studies have employed, the Wisconsin Card Sorting Task, a widely used switching task, to determine that anxiety can result in increased errors (Goodwin and Sher, 1992; Caselli et al., 2004), longer reaction times and general impairments to the switching function of the central executive. In a study Derakshan et al. (2009b) in turn observed that relative to low anxious participants, high trait anxious individuals generally responded significantly slower in a task-switching paradigm than in a single task control condition with the effects of anxiety on task switching being intensified as a function of task complexity. There is however limited direct neural evidence for the presence of impairments of the switching function in anxiety. Ansari and Derakshan (2011b) employed a mixed antisaccade task which comprised of both anti and prosaccade trials with the colour of a fixation cross signalling a pro- or an antisaccade trial. The inter-stimulus interval (ISI) between the cross and target exposure was also manipulated. At a behavioural level the authors observed that at short ISIs, high trait anxious individuals were generally slower to complete an eye movement away from a peripheral target which they were instructed to ignore (i.e. antisaccade trials). However, results revealed that at longer ISIs, no differences in eye-movement latencies were observe across the low and high anxious groups. In terms of neural measures, results revealed that individuals predisposed to show high levels of trait anxiety exhibited greater slow wave negativity as measured by the frontal Contingent Negative Variation (CNV) which is believed to reflect increased cognitive effort as well as the allocation of greater cognitive resources in response to changing task demands (i.e. requiring switching) (Jennings & van der Molen, 2005).

The negative impact of anxiety on attentional control and switching was also observed when using state anxiety measures (Derakshan, Smith & Eysenck, 2009). In this study participants displaying low and high levels of state anxiety were required to perform arithmetical tasks under task-switching or non-task-switching conditions. Results revealed greater negative effects of high state anxiety in the task-switching condition when compared to the non-task-switching condition confirming the idea that state anxiety can lead to impairments of the switching function.

Lastly, ACT also denotes that updating, another executive function of working memory described as the ability to update and monitor representations in working memory can also be disrupted by anxiety. Based on the idea that conflict monitoring is directly associated to the ability to monitor working memory processes (i.e. updating) (Sohn et al., 2007), research has focused on the potential negative impact of trait anxiety on the ability to effectively respond to errors during cognitive tasks. Specifically, Hajcak et al. (2003) investigated the potential impact of anxiety on the event related potential known as the ERN (error related negativity) thought to reflect activity in the ACC and generally presumed to represent an adjustment in attentional control settings following errors on a cognitive task. The author observed that for individuals who were predisposed to show high levels of trait anxiety, anxiety was directly related to the ERN, when making errors on a Stroop task. Specifically results pointed towards a greater ERN which was reflected by enhanced activity in the anterior cingulate cortex (ACC) in high trait anxious participants relative to low-anxious individuals. This indicates that problems with the updating function of WM may also be directly related to elevated levels of anxiety.

1.4.3 Anxiety Related Impairment in Attentional Control in the Presence of Threatening Stimuli

Another important assumption of ACT denotes that anxiety related impairments in attentional control and executive functioning are especially pronounced when threat related stimuli are encountered. This is because the 'bottom up' stimulus-driven attentional system of anxious individuals is thought to be highly responsive to the presence of threatening information (Berggren & Derakshan 2013). As such, anxiety is believed to increase the allocation of attentional resources to threatening stimuli, leaving fewer resources available for current goal-directed tasks. Thus, elevated levels of anxiety are believed to be generally associated with the presence of attentional biases towards threat-related stimuli, reflected by a propensity to preferentially attend to threatening stimuli, relative to neutral or positive ones, while also showing delayed disengagement from such stimuli (Cisler & Koster, 2010, Binsch et al., 2010).

This idea is supported by research employing the dot-probe paradigm originally developed by MacLeod, Mathews, and Tata (1986) which has been widely employed to assess attentional biases to threatening information in anxious populations. Precisely, the dot-probe task was developed to specifically index attentional distribution between simultaneously presented pairs of stimuli differing in emotional valence (e.g. happy faces and angry faces or positive words and negative words). For example, research has shown that, individuals displaying high levels of dispositional anxiety as well as those diagnosed with different types of anxiety disorders, tend to demonstrate a propensity to discriminate probes that appear in the location of threatening stimuli much faster than probes which replace a neutral or positive stimuli, confirming that elevated levels of anxiety are generally associated with an inclination to preferably allocate attention toward threatening stimuli (see Bar-Haim et al., 2007 for a review).

1.4.4 Processing Efficiency vs Performance Effectiveness in Anxiety

Last but not least, despite ACT's strong emphasis on the detrimental impact of anxiety on attentional control, research investigating the negative impact of anxiety on performance in specific cognitive tasks have shown that anxiety does not always directly result in significant differences in the actual quality of performance between high and low anxious individuals (Ansari and Derakshan, 2011b). The authors explain that anxious individuals often engage in compensatory strategies such as allocating additional processing resources and mental effort to counteract the negative effects of anxiety on performance. ACT further denotes that whilst little differences in performance outcomes are usually observed between low and high anxious individuals, the allocation of additional mental or cognitive effort will have important consequences with respect to processing efficiency. Indeed, an important precept of the theory is that anxiety is believed to exert a stronger impact on performance efficiency (e.g. ratio between performance outcome and effort) than performance effectiveness (e.g. performance accuracy), as more resources are invested to obtain the same level of performance that is usually achieved with fewer cognitive resources when anxiety is low, without necessarily sacrificing performance effectiveness.

There is supporting evidence for the idea that anxious individuals generally resort to use compensatory effort in order to maintain optimum levels of performance effectiveness. For example, Dennis and Chen (2009) investigated whether threat-related attentional deficits usually observed in anxiety were relate to changes in cognitive control during task execution using the N2, an event potential believed to represent cognitive control (Folstein & Van Petten, 2008). Results indicated that higher levels of trait anxiety were associated with greater N2 amplitudes during a flanker task involving the presentation of fearful faces. The authors concluded that a greater N2 in anxious individuals may indeed reflect a compensatory mechanism in response to potential attention interference by threats.

1.5 Attention Control and Anxiety in Sports

Based on the original assumptions of ACT, Eysenck and Wilson (2016) recently proposed the Attentional Control Theory: Sport (ACTS), which represents an extension of ACT with direct applicability to sport settings. ACTS takes into account the principal assumptions of ACT about the detrimental impact of anxiety on attentional control. ACTS also encompasses the view that anxiety related impairments to the inhibition and shifting functions of the central executive can impair sports performance, especially when levels of competitive pressure are elevated. In line with this idea research in sports science has provided some support for the idea that a reduced ability to inhibit external as well as internal threatening distractors such as worry, may mediate the anxiety-performance relationship. For example, Wood, Vine and Wilson, (2009) observed that football players taking a series of penalty kicks under pressure displayed longer fixations to the ‘threatening’ goalkeeper and shorter fixations on their target or aiming areas of the goal which negatively impacted penalty taking performance. In addition, this effect was more noticeable when the goalkeeper actively employed distracting behaviours which resulted in shots being kicked closer to the goalkeeper and more attempts being saved. In another study, Englert and Oudejans (2014) in turn revealed that a reduced ability to inhibit internal sources of threat could greatly influence motor performance in sport settings. Specifically, the authors revealed that self-reported levels of distraction and an inability to inhibit distracting thoughts or worries relating to poor performance, mediated the negative impact of anxiety on the performance of tennis players undertaking a serving task. These observations would seem to corroborate the idea that a decreased ability to inhibit negative stimuli such as worries about performance when faced with increased pressure, will have a detrimental impact on performance.

Research in sports has also underlined the importance of the switching function in attaining and maintaining efficient performance. Based on the idea that experienced athletes who are accustomed to perform under pressure should show greater executive control flexibility than those who are less experienced, Han et al. (2014) compared switching abilities in high and low ranking baseball players. The authors observed that high ranking players generally displayed significantly fewer perseverative errors than lower ranked individuals on the Wisconsin Card Sorting, indicating that the more experienced players displayed superior and more flexible shifting abilities than their less experienced counterparts.

Whilst ACTS encompasses most of the original assumptions of ACT in terms of the negative impact of anxiety can exert on executive functioning and attentional control, it is however more explicit about the conditions by which individuals may be predisposed to experience anxiety when performing in competitive pressurised sports contexts. Indeed, the authors suggest that competitive pressure will only lead to elevated levels of state anxiety in sports performers, provided that the presence of cognitive biases influence the perception of the probability and potential consequences of failure during competitions. Specifically, Eysenck and Wilson (2016) argue that whether an athlete will experience anxiety somewhat depends on whether he/she displays attentional biases towards threats, which can themselves be related to the experience of greater levels of anxiety. According to ACTS, a negative attentional bias should predispose an anxious athlete to preferentially attend to threatening information during or prior to the execution of a sporting task (e.g. superior performance by an opponent, past failure), while an interpretative bias might predispose an athlete to interpret his errors as having severe consequences (e.g. missing a shot will lead to the team's defeat or a negative evaluation by peers or coaches). Furthermore, the presence of these cognitive biases are expected to increase pre-existing anxiety levels by altering the perceived probability and the costs of performing poorly. In contrast, ACTS states that the absence of cognitive biases should reduce the amount of state anxiety experienced by athletes facing elevated levels of competitive pressure. This assumption can be explained by the fact that sports performers who do not generally display such intrusive cognitive biases are less likely to interpret mistakes or failures as having dire consequences. These athletes are therefore assumed to be less likely to selectively focus on threatening information or stimuli, which will considerably reduce their perception of the threats associated with sports competitions, and in turn minimise their anxiety symptoms. Thus, anxiety levels may not necessarily be greater under pressure, provided that an athlete does not interpret the pressurised sport competition as threatening.

Initial supporting evidence for the potential involvement of cognitive biases in mediating the anxiety performance relationship originates from Hill et al., (2010) research which explored the impact of cognitive biases on competitive field performance in elite golfers thought to be notorious for either regularly choking or thriving when confronted with high levels of pressure. Results demonstrated that those who were able to maintain high levels of performance under pressure, generally displayed more positive cognitions than those who frequently choked whilst reporting an increase in their levels perceived control. They also reported decreased levels of evaluation apprehension as well as reductions in performance expectations. In contrast, those who had a tendency to choke under pressure reported being highly self-critical of poor performance whilst demonstrating high levels of evaluation apprehension and a reduced ability to control their emotions.

In another study, Nieuwenhuys and Oudejans (2010) analysed the gaze and shooting behaviour of police officers and found further evidence for the presence of attentional biases to threat under conditions of heightened anxiety. In this study, participants performed a shooting task where they were required to fire at different target areas fitted on an opponent. A high anxiety condition involved an opponent (an experienced police instructor) randomly shooting participants with soap cartridges, while in a low anxiety condition, the opponent was a life-size mannequin. Results demonstrated that participants allocated to the high anxiety condition generally took more and longer fixations on the head and gun of their opponents, which can be considered to be threat-related sources of information. Results in turn indicated that participants allocated to the high anxiety condition also achieved lower accuracy on the shooting task.

Importantly, ACTS also states that the anxiety-performance relationship tends to be bidirectional. Specifically the theory argues that the commission of errors can result in elevated anxiety and therefore impact subsequent performance (for example an attempt that directly follows an error). Such idea is supported by previous research by Nicholls et al. (2005), Oudejans et al. (2011) and Buma et al. (2016) who suggested that sports performers will engage in increased levels of worry and error monitoring as a result of committing errors. The authors argued that error monitoring tend to play an important role in the experience of anxiety when performing in pressurised sporting contexts. This idea is in turn widely supported by research emanating from the field of cognitive and affective neuroscience. For example, Aarts and Pourtois (2012) explored error monitoring processes using the ERN, an event related potential reflecting error monitoring, in low- and high-anxious individuals undertaking a lab based cognitive task. The authors observed that elevated levels of anxiety significantly disrupted the evaluative component of performance monitoring. In addition, Moser et al., (2013) in turn reported that anxiety was generally associated with an enhanced ERN with high- anxious individuals generally engaging in greater amounts of error monitoring than low-anxious ones. As highlighted above ACTS also states that the presence cognitive biases will greatly influence whether individuals will engage in excessive levels of performance motoring when faced with anxiety provoking situations.

Finally, as with ACT, the principal assumption of ACTS denotes that anxiety generally impairs attentional control. However, Eysenck and Wilson (2016) also argue that attentional control disruptions do not occur at all times throughout a competition, but are rather sporadic and occur at specific intervals when state anxiety levels are most elevated (e.g. after failure, after a missed shot). The ACTS indicates that when such disruptions occur, performance is likely to be seriously impacted.

In sum, attentional control appears to be indispensable to achieve and maintain optimal performance in various sporting disciplines (Janelle, 2002; Nieuwenhuys & Oudejans, 2012, 2017). More specifically, the ability to maintain optimal levels of attentional control when faced with increased level of pressure is directly related to the ability to maintain optimal levels of motor performance (Vine, Lee, Moore, & Wilson, 2013). Whilst most research designed to investigate the negative impact of anxiety on attentional control in the field of cognitive and affective neuroscience have used computer-based cognitive tasks to assess attentional control, this is has not yet been done in the in the sports field. Researchers in this area have instead resorted to using specific gaze behaviours which they believe, may represent indices of attentional control in sports (see Vickers & Williams, 2007).

1.6 Gaze Behaviours in Sports

1.6.1 The Quiet Eye

In order to understand how anxiety-induced changes in attentional control may affect sport performance, it is essential to identify methods that can be employed to objectively to measure attentional control in the sports field. The development of light and portable eye tracking equipment has enabled researchers to explore the gaze behaviours of athletes when undertaking live sporting tasks. More specifically, a large body of research in this area has employed gaze behaviours as indices of attentional control in sports (see Wilson 2012 for a review).

Such idea emanates from the view that gaze orientation is believed to be determined by top-down attentional control which is in turn thought to be dependent on task-specific demands and objectives (Land, 2009). Furthermore, the idea of using gaze indices to determine levels of attentional focus during live sporting task is based on the assumption that a shift in gaze to a new location is also indicative of a shift of focus to that location. Whilst a point of gaze can be dissociated from a point of attention, there is a general consensus that a shift in visual orientation is generally followed by a shift in attention (Mann et al., 2007). This argument is further reinforced by findings demonstrating that the neural structures that control saccadic eye movements (i.e. eye movements between fixations) are equivalent to the ones that are believed to control shifts of attention (Corbetta, 1998).

One gaze behaviour that has been vastly explored as a potential index of attentional control in sports is the quiet eye period (QE; Vickers, 1996). The QE refers to the length of the final fixation or tracking fixation on a location or relevant target within 1 or 3 degree of visual angle, occurring before the initiation of a motor movement and lasting for a minimum of 100ms. This fixation was initially theorised to reflect the organization of visual attentional control parameters of perceptual-motor behaviour. Research on the QE also suggests that this specific gaze behaviour serves to ensure efficient pre-planning of motor responses (Klosterman Kredel & Hossner 2013; Mann et al., 2007) while helping sports performers to maintain efficient online control under visual guidance (Vine, Moore & Wilson, 2013). The QE has been shown to underpin successful performance in diverse sporting disciplines while reflecting both expertise (inter-individual) and proficiency (intra-individual), with expert performance and successful attempts in sporting tasks being generally characterised by longer QE durations (Wilson, 2012). For example, Vickers (1996) who conducted the first study on the QE in basketball free-throw shooting, observed that expert basketball players generally displayed significantly longer and earlier final fixations (i.e. QE durations) on the hoop when compared to a group of less experimented players. Additionally, results indicated that both experts and near-experts displayed significantly shorter QE durations when they missed a free throw compared with successful attempts. Comparable findings were subsequently observed in other sporting disciplines which involved both aiming and tracking sporting tasks such as dart throwing (Vickers, Rodrigues, & Edworthy, 2000), rifle shooting (Janelle et al., 2000), billiards potting (Williams, Singer, & Froehlich, 2002), golf putting (Wilson & Pearcey, 2009) and shotgun shooting (Causer, Bennett, Holmes, Janelle, & Williams, 2010).

1.6.2 The Quiet Eye in Tennis

Whilst a large body of research exploring the quiet eye has involved self-paced sporting tasks which mostly require aiming such as golf putting, basketball free throw shooting or football penalty taking, research has also been conducted in sporting disciplines which require tracking such as clay pigeon shooting (Causer et al., 2011) or hockey goal tending (Panchuk, Vickers & Hopkins, 2017). There is however limited research exploring the QE in fast paced interceptive sports such as tennis. In one study conducted in lab settings, Park (2005) examined the gaze behaviours of tennis players undertaking a set of volleys. Results revealed earlier QE onset and longer QE durations on hits when compared to shots that were missed. However the fly path of a tennis ball from a regular shot hit from the baseline is complex and may require several periods of tracking (e.g. from the moment the ball is hit by the opponent, after the ball has bounced and around the time of contact of the racket with the ball). In a recent study, Sáenz-Moncaleano, Basevitch, Tenenbaum, (2018) explored the QE in experts and non-experts tennis players undertaking a return of serve in a tennis task which was set in natural setting. Results confirmed that several periods of tracking were required in tennis. Results also indicated that expert tennis players exhibited better return shots than their lower skill counterparts with high-score shots being characterized by earlier (QE onset) and longer fixation durations (QE) on the ball at pre-bounce. The authors did not however observe any significant differences between experts and non-experts on the later stages of the ball’s flight path (i.e. ball tracking post bounce).

1.6.3 The QE as an Index of Attentional Control in Sports

Recent evidence suggests that the QE may represent a useful index of optimal attentional control in natural settings in sport (e.g. Behan & Wilson, 2008; Causer et al., 2011b; Vickers, 1996; Wilson et al., 2009). Such idea can be explained by findings emanating from research conducted in the field of cognitive-neuroscience (e.g. Corbetta, Patel, & Schulman, 2008) which emphasises the importance of attentional control in goal-driven tasks (Land, 2009). Indeed, Vickers' (1996) initially theorised that longer QE periods may allow performers an extended duration of response programming, while minimising distraction from other cues (i.e. internal of external) which falls in line with Corbetta's et al. (2008) theoretical model of attention emphasising the delicate balance between a goal-directed, top down and stimulus-driven, bottom-up system. More specifically, in relation to this model, the QE would serve to maintain effective goal-driven attentional control, while reducing the impact of the stimulus-driven attentional system. More research is however still needed to fully establish the specific cognitive mechanisms which underpin the QE phenomenon as an index of attentional control in the sports field.

1.6.4 Alternative Gaze Indices of 'Attentional Control' in Tennis

It may be possible to measure attention control in an interceptive task such as tennis, using alternative indices of gaze behaviours. For example Mann et al. (2013) studied the gaze behaviours of cricket batsmen and found that elite players displayed characteristic eye movement strategies permitting a precise prediction of bat-ball contact. Specifically, the authors observed that by moving their eyes away from the ball and into the contact zone, elite batsmen were capable of accurately predicting the location of the ball-bat contact point based on the initial trajectory of the ball following the bounce. Such patterns of gaze behaviours have also been observed in tennis. Lafont (2007, 2008) conducted a detailed photo analysis of elite tennis players and observed that the top world ranking tennis players generally displayed a characteristic head (eye) fixation toward the area of contact with the ball from before contact but also through the early phase of the follow through. In some case a steady fixation was even observed as late as when the ball was already on its way towards the opponent. Lafont (2007, 2008) consequently argued that this specific gaze strategy may represent an index of visual attentional control in tennis, resembling the late portion of the QE which could in turn be reminiscent of superior tennis performance. This suggestion is consistent with recent findings by Sáenz-Moncaleano et al. (2018) who observed that during a serving task, high skilled tennis players displayed a higher percentage of shots where the racket-ball contact occurred in their central vision (i.e. foveal vison) when compared to the an intermediated-skill group. Finally Lafont' (2007, 2008) suggestion is consistent with previous research in golf (Vine et al., 2013), which demonstrated that unsuccessful putts generally resulted from a shorter fixation on the ball at the time of impact and an earlier attempt to direct gaze towards the hole (i.e. impaired inhibition). Thus, using portable eye tracking equipment during a simple volleying tennis task where players are required to aim their shots to a target, it should be possible to evaluate tennis players' ability to maintain a steady fixation on ball-racket contact and their ability to 'inhibit' the action of directing their gaze to the target (i.e. checking the outcome of their shots).

1.7 Competitive Anxiety and the Quiet Eye

Whilst the QE has been shown to represent a valid index of task proficiency and expertise in diverse sporting disciplines (Vickers, 1996; see Lebeau et al., 2016 for a recent meta-analysis), it is has also been shown to be highly sensitive to the detrimental impact of competitive pressure and anxiety. Indeed, research has shown that competition related anxiety can result in QE reductions in self-paced sporting tasks, such as golf putting (Vine et al., 2013), basketball free-throw shooting (Wilson, Vine, & Wood, 2009), shotgun shooting (Causer et al., 2011) and archery (Behan & Wilson, 2008). For example, Behan and Wilson (2008) evaluated anxiety-related changes in the QE period and shooting accuracy in a simulated archery task performed under low and high anxiety conditions. Results revealed that the QE period was significantly reduced when participants were faced with elevated levels of pressure with shooting accuracy being greatly influenced by the duration of the QE and with shorter QE periods being associated with decreased performance.

In another study, Wilson et al. (2009) explored the negative impact of anxiety on the QE during a basketball free-throw shooting task. Precisely, participants undertook a free throw shooting task following a pressure manipulation and displayed reduced QE durations whilst showing a tendency to make more fixations around vicinity of the hoop. The adverse impact of anxiety on the QE period was further investigated in golf putting (Vine et al., 2013). In this study, expert golfers were required to perform a series of putts under elevated levels of pressure with QE periods being examined at three specific time points, prior to the backswing (QE-pre), during the putting stroke (QE-online) and after ball-putter contact (QE-dwell). Results indicated that QE durations were significantly shorter for missed putts performed under pressure, emphasising the detrimental impact of anxiety on the QE. Importantly, measuring QE durations at different time points enabled the authors to establish that anxiety had a greater impact on visual attentional control during and after movement execution, rather than before the initiation of a motor action. Finally, the negative effects of anxiety on the QE have also been found in sporting tasks which involve tracking an object. For example, Causer et al. (2011b) observed expert shotgun shooters undertaking a clay pigeon shooting task, that elevated levels cognitive anxiety resulted in a decrease in shooting performance and shortened QE durations (i.e. the length of gaze tracking on the clays) which were characterised by a delayed onset of the QE.

The findings presented above largely suggest that reductions in the length of the QE period may be largely related to anxiety-induced deficits in attentional control processes. Indeed the negative impact of anxiety on gaze behaviours, such as reduced QE durations observed when performing under pressure in different sporting disciplines, can be explained by one of the principal assumption of ACTS. Specifically as with ACT the theory argues that anxiety tends to disrupt the balance between the top-down goal-directed system (dorsal attentional system) and the bottom-up stimulus-driven system (ventral attention), promoting the latter and therefore making athletes more susceptible to distraction and less able to direct their attention on goal-directed tasks (Wilson & Eysenck, 2016). Thus, in terms of the QE, it is assumed that pressure related anxiety will result in increased distractibility and potential disruptions to the inhibition and switching functions of the central executive which will then disrupt QE processing as well as visuomotor preparation and online control, leading to impaired motor and task performance. Consequently, longer QE durations before and during the execution of a motor sporting task performance are believed to be required to enable athletes to suppress distracting stimuli whether external or internal such as emotions or worries to enable the dorsal attentional system to successfully execute a motor action as planned.

1.8. Quiet Eye Training

As explained above, utilising optimal gaze strategies such as the QE appear to be essential to achieve successful sporting performance. This is especially relevant when sports performers are confronted with elevated pressure with the QE appearing to be highly vulnerable to the negative impact of competition related anxiety. Consequently, researchers in the area of sports have developed and implemented tailored QE training interventions with the aim of improving gaze behaviour to enable athletes to better cope with the negative impact that competitive anxiety can exert on field performance. Specifically, based on the assumption that the QE may represent an index of attentional control, QE training methods have been developed in an attempt to ‘enhance’ attentional control in the field and improve sports performance under conditions where athletes are faced with elevated levels of pressure.

QE training interventions generally involve guiding decisions in terms of when, where and how to fixate specific areas of interest in the visual scene when undertaking a sporting motor skill (Wood & Wilson, 2011). Specifically, QE training protocols involve exposing athletes to video feedback displaying gaze strategies (i.e. the QE) employed by expert performers as well as providing verbal feedback about the QE. This type of training intervention has been shown to facilitate optimal gaze strategies and results in performance improvements in various sporting disciplines, such as golf putting (Vine, Moore, & Wilson, 2011), free-throw shooting (Harle & Vickers. 2001) and clay pigeon shooting (Causer et al., 2001b). For example Harle and Vickers (2001) who conducted the first QE training study on near elite basketball players undertaking a self-paced basketball free throw shooting task, showed that compared to a control group, a QE trained group displayed increased QE durations and enhanced free throw performance. Importantly, over a full season the trained group improved their free throw shooting percentage by 23% which was not the case for their control group counterparts. In another study, Causer et al., (2011) explored the utility of QE training in 24 international level skeet shooters two were allocated to QE trained or control group. During an 8-week training period the QE trained group watched video feedback of their eye movements and practiced a pre-shot routine aimed at lengthening their QE. Results revealed positive effects on gaze behaviours and shooting performance with the QE trained group displaying significantly earlier QE onset on the clay pigeon as well as longer QE periods, whilst demonstrating significantly improved performance on the shooting task. This was however not the case for the control group who revealed no significant changes in QE durations or shooting performance.

Most importantly, QE training interventions have also largely emphasised the efficacy of QE training in protecting sports performers against the negative impact of anxiety on performance. For example Vine and Wilson (2010) and Vine et al., (2011) employed QE training interventions with both novice and expert golfers undertaking a golf putting tasks. In both studies results indicated that participants allocated to a QE training group were able to maintain more efficient

QE durations as well as golf putting performance in a high anxiety condition compared to a low anxiety retention condition. This was not the case for their control group counterparts who had solely been given technical instructions and displayed significantly shorter QE and impaired putting performance during the pressure tests. Finally, Moore, Vine, Cooke, Ring and Wilson (2012) examined the impact of QE training on golf putting performance and observed that adopting an expert like QE was especially beneficial when participants were required to perform under pressure. Specifically, following a period of QE training, a sample of golfers displayed longer QE durations and enhanced physiological responses compared to a control group who solely received technical training. Results also indicated that the QE trained group displayed higher putting accuracy than their control group counterparts whilst showing slower club head acceleration, less muscle activity before the shot and greater heart rate deceleration.

1.8.1 Limitations of QE Training Methods

Whilst QE training methods have been shown to equip athletes with an enhanced ability to cope with the potential burden of performing under elevated levels of pressure in diverse sporting disciplines, such training methods however represent a number of important limitations. First, QE training interventions tend to be task specific and largely based on the observation of an expert model. Second, due to the explicit nature of the instructions employed during QE training interventions, it is not possible to identify whether training gains in gaze duration and field performance in simple sporting tasks such as golf putting or penalty taking can be directly attributed to the enhancement of specific neural mechanisms relating to attention control or whether performance improvements are merely related to the explicit nature of the verbal instructions employed (i.e. ensure gaze is in the ball, final fixation should be on back of the ball).

Consequently, the specific cognitive mechanisms by which QE training methods exert their effects on performance remain largely undetermined (Vine, Moore, & Wilson, 2014) and it is therefore difficult to draw definite conclusions about the role of attentional control and the efficiency executive functions of WM in moderating the QE and sports performance under pressure. For example, it could be argued that rather than directly impacting on specific attentional control mechanisms such as inhibitory control of shifting of attention, QE training may promote specific strategies known to benefit efficient performance in pressurised contexts such as enhancing an external focus of attention (Wulf , 2007).

In sum, by elaborating alternative lab based cognitive training paradigms specifically designed to target training towards specific mechanisms of attention control as specified by ACT, it may be possible to implement more effective training methods which will not rely on explicit verbal instructions and that could be easily applied in sport settings to reduce distractibility, enhance attentional control and improve field performance. Furthermore, employing such training methods in sports would in turn allow to further explore and verify the validity of the QE as an index of attentional control in sports.

1.9 Lab Based Cognitive Training Methods

1.9.1 ABM Training

In the area of cognitive and affective neuroscience, researchers have started to develop laboratory based cognitive training paradigms to specifically target anxiety symptoms. One paradigm that was initially developed to target anxiety symptoms is the Attention Bias Modification task (ABM). The idea behind this lab based training intervention was that anxiety related attentional biases could potentially be altered by training individuals to repeatedly shift their attention away from a threatening stimuli to a neutral or positive one. Indeed, as it was mentioned earlier, a large number of studies in the area of cognitive and affective neuroscience have established that higher levels of anxiety are generally associated with an inclination to preferably allocate attention toward threatening stimuli (see Bar-Haim et al., 2007 for a review). ABM computer based training interventions were initially developed to determine the causal implication of attentional biases in anxiety, and by modifying them, target anxiety related symptoms (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker 2002; Linetzky, Pergamin-Hight, Pine, & Bar-Haim, 2015). Attentional bias modification (ABM) training tasks are based on the dot-probe attentional bias assessment task in which participants are required to detect a probe that appears in place of either a positive or negative stimuli (i.e. angry or happy face) with faster reaction time to detect a probe that appearing behind a negative stimulus relative to a neutral or positive one, indicating an attentional bias towards such stimuli. However, the ABM training task includes a contingency where the avoidance of negative stimuli is encouraged by always placing a probe behind a neutral or positive stimulus. The idea being, that participants undertaking this intervention, will show a reduction in bias towards threats following a period of training (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002).

Several studies have demonstrated that attentional biases to threats can be reduced in emotionally vulnerable populations to show positive effects on anxiety symptoms (Hayes, Hirsch, and Mathews, 2010; Notebaert, Clarke, Grafton, MacLeod, 2015, Hakamata, Lissek, Bar-Haim, Britton, Fox, Leibenluft et al., 2010; Clark & Macleod, 2014). In addition, ABM training methods have also been shown to be helpful in contexts where individuals are confronted with performance related stressors. For example, MacLeod, Rutherford, Campbell, Ebsworthy, and Holker (2002) demonstrated that it was possible to reduce attentional biases to threat in non-anxious participants using an ABM intervention which resulted in an alteration to their emotional responses when undertaking a stressful anagram task. Comparable results with ABM training were also obtained with children who showed no signs of raised levels of state anxiety when undertaking a puzzle task under pressure (Eldar, Ricon & Bar-Haim, 2008).

Nevertheless, whilst ABM training methods have shown some benefits in terms of reducing anxiety symptoms or increasing individuals' ability to perform cognitive tasks efficiently under elevated levels of pressure, it has also been argued that such methods may encourage specific strategies rather than specifically target executive function and attentional control per se (Cisler & Koster 2010). More importantly, recent research exploring the efficacy of ABM training on anxiety, strongly suggests that the positive benefits of ABM training on anxiety symptoms may be largely related individuals' initial levels of attentional control. More precisely, Basanovica, Notebaert, Grafton, Hirsch, Patrick and Clarke (2017) observed that individuals who were more likely to benefit from ABM training (i.e. show a decrease in their attentional bias to threat) also displayed higher baseline levels of attentional control. Indeed, the authors observed that individual differences in two aspects of attentional control such as inhibitory control and control of attentional selectivity, were positively associated with individual differences in the magnitude of attentional bias changes displayed following an ABM intervention. These findings strongly suggest that, when attempting to target attentional biases to reduce the negative impact of anxiety on cognitive performance, it may be also useful to employ lab based cognitive training methods which have been shown to enhance attentional control and the processing efficiency of the main functions of the central executive.

1.9.2 Working Memory Training

A large growing body of research have emphasised the efficacy of lab based cognitive training paradigms believed to enhance working memory capacity to facilitate attentional control processes. Such idea is based on the development of recent working memory (WM) models (see Unsworth et al., 2012), which propose that attentional control directly relates to the relative efficacy of the main central executive functions of WM (particularly the inhibition, shifting, and updating functions) in attaining a task goal. Indeed, as it was highlighted earlier, research emanating from the field of cognitive neuroscience has emphasised a direct relationship between WMC and attentional control (Engle, 2002; Kane, Conway, Ham brick, & Engle, 2007). More precisely, attentional control is often being referred to as the ability to direct attention toward goal-relevant information and away from distractions (Hutchison, 2007; Unsworth, Schrock, & Engle, 2004). Consequently, Shipstead et al. (2012) suggested that WM training methods specifically designed to increase working memory capacity and processing efficiency may enhance attentional processes and help individuals become generally more attentive in their daily activities.

Recent developments in the area of cognitive training have led to the elaboration of lab based training paradigms specifically designed to enhance attention control processes in the absence of emotional stimuli by increasing the influence of goal directed processes employing tasks specifically designed to increase WMC (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008). For example, Jaeggi et al. (2008) demonstrated that WMC in healthy participants can be improved employing an adaptive training version of dual n-back task. When undertaking training on the dual n-back task, participant are presented with a sequence of paired audio and visual stimuli and are required to determine whether either one or both of a currently presented pair matched those previously presented on a selected number of trials (n) back in the sequence. Task difficulty is also adjusted dynamically by increasing or decreasing n-back levels, based on participants' previous performance. In their initial work Jaeggi et al. (2008) observed WMC gains in a sample of participants relative to a control group as a result of extended training on the dual n-back task (e.g. 17 and 19 days). Importantly, the authors also found transfer effects of training on indices of adaptive reasoning (i.e. fluid intelligence). In another study, Buschkuel, Jaeggi, Hutchinson, Perrig-Chiello, Däpp et al. (2008) observed that training a sample of older adults on the dual n-back task resulted in increased memory performance relative to a control group.

This increase in performance was observed to be especially pronounced on indices of visual working memory.

1.9.3 Working Memory Training in Emotionally Vulnerable Populations

Whilst a large body of research has demonstrated the utility of WM training in enhancing WMC and attentional processes in healthy populations, recent encouraging advances in the field of cognitive and affective neuroscience have also emphasised the usefulness of WM training in reducing anxiety and depression symptoms in emotionally vulnerable population. For example, Owens et al. (2013) initially demonstrated that following a period of two weeks of training on the adaptive dual n-back task, dysphoric (subclinically depressed) individuals generally displayed enhanced filtering efficiency on a change detection task employed to assess visual WM. These training effects which were observed at behavioural and neural levels indicated that enhancing WMC can contribute to enhance attention control processes and processing efficiency in emotionally vulnerable individuals. In another study, Schweizer, Grahn, Hampshire, Mobbs and Dalgleish (2013), employed an emotional version of the dual n-back task which included emotional faces as visual information and emotional words as auditory information. Results indicated that training on the emotional version of the dual n-back task, resulted in enhanced emotion regulation in response to negative film clips. Precisely, transfer effects of training were observed in terms of the subjective levels of distress that was reported by participants after watching emotional clips with participants also displaying an increase activity in frontal brain areas thought to be involved in affective control. Lastly, research by Siegle, Price, Jones, Ghinassi, Painter and Thase (2014) also tested the utility of WM training in depression by employing an adaptive version the Pace Auditory Serial Addition Task (PASAT). Results indicated that training on this adaptive PASAT task, lead to reduced rumination as well a reduction in depressive symptomatology in individuals diagnosed with Major Depressive Disorders (MMD). In a subsequent study, Hoorelbeke, Koster, Vanderhasselt, Callewaert and Demeyer (2015) employed the same WM training task and showed reduce emotional reactivity and brooding in undergraduate students believed to be at risk for developing depressive symptomatology.

There is also growing evidence supporting the utility of WM in anxiety. First of all, in a recent study, Sari, Koster, Pourtois and Derakshan (2016) explored the potential benefits of cognitive training employing a non-emotional version of the adaptive dual n-back task to assess the potential impact of WM training in a sample of high trait anxious participants. The authors observed that training for a period of three weeks on the adaptive dual n-back previously employed by Owens et al. (2013) lead to improved attentional control as measured by a flanker task. Training also resulted in changes in resting state EEG believed to reflect attentional control. Furthermore, Sari et al. (2016) in turn reported that the degree of improvement on this neutral version of dual n-back training task correlated with greater reduction in self-reported trait anxiety across the training period. Course-Choi, Harris and Derakshan (2017) in turn observed that following the completion of a training programme on the dual n-back task which was conducted in conjunction with meditation training, participants who displayed high levels trait worry (i.e. characteristic of anxious populations) displayed a significantly greater reduction of their anxiety symptoms when compared to participants who solely undertook meditative training. Finally, employing the same training task, Holton, Derakshan and Fox (2018) recently demonstrated that training-related improvements on the dual n-back training task through a two weeks training period, were generally associated with gains in working memory capacity and reductions in worry symptoms. Similarly, Grol et al. (2018) recently found that increases in working memory performance following training on the dual n-back training task, were directly related to a reduction in reactivity of negative intrusions to a worry period. Taken together these encouraging findings strongly suggest that, it may be possible not only to isolate but also to train specific functions of the central executive of WM in order to enhance attentional control and reduce anxiety related distractibility and enable individual to better cope with negative impact of anxiety on cognitive performance.

1.9.4 Visual Search Training and Anxiety

A training version of the attentional capture task popularised by Theeuwes (1992) could be potentially be employed to directly target top down control and inhibitory processes. Indeed, while this task has traditionally been thought to necessitate automatic capture of attention, de Fockert and Theeuwes (2012) argued that in order to overcome automatic capture of attention by singleton distractors when undertaking and attentional capture task, top down control is necessary to achieve optimum levels of performance.

Employing a visual capture task analogous to Theeuwes' (1992) original task, Moran and Moser (2014) observed that trait anxiety was associated with impaired attentional control when identifying a target in the presence of a salient singleton distractor. Specifically, high trait anxious participants displayed behavioural slowing on the visual search task. They also showed an enhanced N2pc (an event-related potential which reflects a neural index of attentional selection) when the distractor was located in the vicinity of the target and required top down control in order to inhibit it. In a follow up study Moser, Moran and Leber (2015) further tested the idea that manipulating attention to salient, but non emotional, distractors following a single training session on a visual capture task, would directly influence the experience of state anxiety in trait anxious individuals. Results revealed that training participants to attend to a singleton distractors resulted in increased attention to such distractors and increased levels of self-reported state anxiety which was more pronounced in high trait anxious individuals. On the other hand, feature search training which required the inhibition of salient distractors resulted in an increased ability to inhibit singleton distractors (i.e. improved inhibitory control) while state anxiety remained at initial levels.

These findings confirm that it may be possible to employ an attentional capture task as a training paradigm in order to directly target the inhibition of salient distractor and top down control processes. Indeed, it is highly possible that over-continuing exposure on such task and repeatedly engaging in the inhibition of salient distractors in target identification, may indeed lead to training related gains in terms of inhibitory control. Such task could therefore be employed to develop an alternative training paradigm directly targeting top down control processes to decrease the negative impact of anxiety attentional control processes and performance

1.10 Cognitive Training Methods in Sports

Beside QE training methods highlighted earlier, researchers in sports have also attempted to enhance 'cognitive abilities' in sports by employing diverse training methods. For example, Perceptual Cognitive Training Techniques (PCT) have been widely employed by researchers in the sports field. Perceptual-Cognitive skills in sports are thought to reflect an athlete's ability to localise, identify and process environmental cues and to assimilate them with existing knowledge and motor abilities in order to select and execute appropriate motor skills needed to achieve efficient performance (Broadbent et al., 2015). As such, PCT is a training technique which was developed with the aim to train perceptual and sensory functions believed to be necessary in decision-making and anticipatory skills in sports. This training method involves watching life-sized videos which are used to directly replicate key situations from the performance environment to enhance athletes' 'cognitive functions' believed to be necessary to achieve optimal levels of performance when undertaking a real world sporting task (Williams et al. 2002). This approach has shown some benefits of training for cognitive skills such as decision making and anticipation in sporting disciplines such as tennis and penalty kicking in football (see Broadbent et al., 2015 for review). Nevertheless, an important limitation of the PCT training paradigm is that whilst transfers of training are usually observed on lab based indices resembling the actual training task, there seems to be limited evidence for far transfer of PCT training on actual field performance (Broadbent et al., 2015). Additionally, as with QE training, these methods tend to be task specific and do not directly target specific cognitive functions, making it difficult to directly unravel the specific cognitive mechanisms (if any) by which training may lead to performance improvements.

Lastly, in recent years, commercially available cognitive training devices (CACT) developed to target cognitive processes in athletes, have in turn become popular for use in sports. In short, these training devices are usually advertised as enhancing processes such as attention and decision-making by directly targeting cognitive functions. One popular intervention is the 'Neurotracker training device' developed by Faubert (2013). This intervention requires participants to undertake a three dimensional multiple object tracking task (3D-MOT) which is projected on a large screen. During this task, athletes are required to track multiple moving objects in a dynamic and changing visual scene and make decisions in relation to the location of several targets. This training intervention has been advertised as being beneficial for team sports performance, where athletes must be able to simultaneously process different sources of information critical for efficient performance such as the position of multiple teammates or opponents as well as the location of potential obstacles and targets such as the goals in football or the hoop in basketball. Whilst Faubert (2013) observed that expert athletes in diverse sporting disciplines tend to excel at this task, research by Romeas, Gudner and Faubert, (2008) conducted on a sample of football players, in turn found some transfer effect of training on an index of on-field passing decision making.

Nevertheless, Harris, Vine and Wilson (2018) recently explained that studies which are being conducted to assess the utility and the scientific validity of such commercial training device have been largely criticised for not employing adequate procedures in terms of using passive rather than active groups (see Simons et al., 2016). Another problem resides with the fact that research examining the validity of such training devices is so far very limited. Harris, Wilson and Vine

(2018) also argued that there is little (if any direct) evidence that undertaking training employing CACT devices can actually benefit field sporting performance.

While these trainings methods claim to target cognitions in sports more empirical research employing sound scientific methods is needed to explore whether lab based cognitive methods can benefit sports performance. Additionally, more research is also required to draw clear conclusions in terms of the neurocognitive mechanisms which may be responsible for athletes displaying impaired sports performance when faced with anxiety provoking situations. To date there is no research in the area of cognitive training and sports science that has attempted to use lab based cognitive training methods in controlled lab settings and sporting environments to directly target mechanisms of attentional control as well as attentional biases toward threats to protect sports performers against the negative impact of pressure related anxiety on sports performance. Employing cognitive training methods may allow to further explore the potential link between deficient attentional control and impairment in sports performance. Specifically, if a training paradigm designed to target specific cognitive functions does result in performer's showing training related gains on sport performance under pressure, it may be possible to infer that such functions may be directly related to the negative impact of pressure on performance in goal directed sporting tasks.

1.11 Summary

In summary, a large body of research has underlined that anxiety can severely interfere with task performance in athletes engaging in competitive sporting activities. Anxiety related impairments on sports performance have been largely attributed to disruptions to attentional control. Indeed, the Attentional Control Theory (ACT) specifies that anxiety generally impairs the relative efficiency of the central executive functions of working memory by increasing the influence of stimulus driven processes and resulting in greater distractibility and impaired performance when undertaking cognitive tasks. Drawing from ACT, sports scientists have in turned suggested that issues related to the top down regulation of goal directed behaviour can lead to heightened levels of distractibility and negative thoughts about performance outcomes, especially under pressurised situations, hindering the control of skilled movement execution leading to impaired performance (Wilson and Eysenck 2016). The Quiet Eye (Vickers, 2007) thought to represent a specific index of optimal attentional control promoting efficient motor performance, has received ample empirical support in the sports psychology literature as a potential index of attentional control in the sports field.

In addition, support for the role of the QE in protecting motor and general performance against the negative impact of anxiety has been provided by research which has employed interventions designed to train performers to extend their QE period via video feedback of gaze behaviour and verbal instructions (see Vine et al., 2014 for a review). However, such training methods tend to be task specific and due to the explicit nature of the instructions employed by this types of interventions, it is not possible to identify the specific cognitive mechanism by which training may result in improved or resilient sports performance. Additionally, such training methods do not allow to draw clear conclusions in terms the assumptions of ACT and ACTS which underline the detrimental impact of anxiety on attentional control and sports performance. Whilst different types of cognitive training interventions have been employed in sports, the evidence for potential gains on performance is limited and most interventions have not been employed to protect sporting performance in pressurised contexts. Nevertheless, recent encouraging developments in the area of cognitive training strongly suggest that attention as well as working memory can be trained to result in positive performance outcomes in normal and emotionally vulnerable populations. Specifically, three singular lab based cognitive training paradigms such as ABM training, dual n-back working memory training and visual search training have the potential for use in sports to protect individuals against the detrimental impact of pressure related anxiety.

1.12 Research Aims and Thesis Outline

The aims of the current PhD thesis are two-fold. The first aim of this PhD thesis is to develop and implement lab based cognitive training interventions to counter the negative impact of anxiety on field sports performance. Specifically, capitalising on promising cognitive training techniques which have been previously employed in the fields of cognitive and affective neuroscience, the principal aim of the thesis is to employ lab based cognitive training paradigms to target executive functions of working memory as well as attentional biases to threat to reduce the negative impact of anxiety and promote efficient field performance in tennis players facing elevated levels of competitive pressure. Second, findings emanating from these different training experiments along with the results of a final experiment designed to explore neural indices of cognitive control and performance monitoring such as electrophysiological ERP indices (i.e. theN2 and the ERN) in tennis players, will serve to verify the recent assumptions of ACT and ACTS. Potential findings will also serve to further verify the potential cognitive mechanisms by which the experience of pressure related anxiety in sporting contexts, generally leads to impairments in motor and task performance. Last but not least, potential transfer effects of training will also contribute to draw clearer conclusion in terms of the relationship between gaze behaviours and attentional control in sports.

The principal aim of Chapter 2 will be to investigate if training inhibitory control using a novel attentional capture task designed to promote the inhibition of distractors in target identifications, can also show benefits for performance on an antisaccade task and promote efficient gaze behaviour in tennis as well as general performance on a tennis task performed under pressure. In Chapter 3, the dual n-back training paradigm previously shown to enhance WMC, will be employed to investigate whether general gains in working memory capacity and attentional control can protect tennis players against the negative impact of anxiety and show transfer of training to tennis performance, on the quiet eye as well as on a general measure of working memory capacity. Using a novel tennis specific ABM training task, Chapter 4 will explore whether training tennis players to either attend to negative or positive stimuli, in a single ABM training session, will result in transferrable effects on a dot-probe task designed to index attentional bias in sports, as well as sports performance outcomes and indices of attentional control in tennis (i.e. the QE). Lastly, the principal aim of Chapter 5 will be to identify whether neural correlates of error monitoring (i.e. the ERN) and cognitive control (i.e. the N2) will modulate the attentional bias-performance relationship in a sample of experienced tennis player and whether these neural indices are related to sports performance and the quiet eye in a tennis volleying task performed under pressure.

1.13 Methodology of Eye Tracking Data Collection and Analysis

1.13.1 Eye Tracking Equipment

SMI portable eye tracking glasses (Fig 1.1) were used in Experiment 3 of Chapter 2 to track eye movements and gaze. The SMI glasses employ active infrared lighting sources with the surface of a cornea being viewed as a mirror. When light falls on the curved cornea of the eye, a corneal reflection ensues. The gaze point can thus be uniquely determined by tracking this reflection using a camera. The SMI glasses track both of the two eyes with automatic parallax compensation at a sample rate of 30Hz, and also include a central scene camera that records an egocentric view of the world in high definition (HD) at a resolution of 1280 × 960 at 24 frames per second. The field of view of the scene camera is 60 degree (horizontal) and 46 degree (vertical). The output of the eye tracking is the 2D gaze point on the image plane of the egocentric video. The accuracy of gaze point as been calculated to be within 0.5 degree. The SMI ETG 2.0 records onto an adapted Samsung Galaxy smartphone which can easily be attached to performers, allowing free movement when undertaking a sports task. All data is stored on the Samsung unit and later downloaded to a computer for analysis. Before tracking can be started each participant undertakes 3 point calibration procedure which involves detecting specific markers in the visual scene.

Figure 1.1: *SMI head mounted portable eye tracking system*

Pupil labs portable eye tracking glasses were employed in chapter 3 4 and 5. The Pupil lab mobile eye tracking headset (see figure 1.2) includes one scene camera and two infrared (IR) spectrum eye cameras employed or dark pupil detection. All cameras connect to a laptop, desktop, or mobile computer platform via high speed USB 2.0. The camera video streams are read employing Pupil Capture software for real-time pupil detection, gaze mapping and recording. The Pupil-lab eye tracking glasses utilise the same principles as the SMI glasses to capture corneal reflection however the eye cameras can record eye movements at a sample rate of 30, 60 or 120 Hz. The central scene camera can in turns captures the egocentric view of the world at 30hz with resolution of 1080p, 60hz at 720p or 120hz at vga. The Pupil lab systems employs normalized 2D gaze position. Gaze accuracy for this system has been estimated at 0.60 degree with gaze precision being estimated at 0.08 degrees. The Pupil Capture software is used to capture live gaze and map gaze to the world view captured by the scene camera. The Pupil Player software is used to playback and visualize and download video and gaze data initially recorded with Pupil Capture. All eye tracking data were stored on a MacBook personal computer which was also so used to run the different software. As with the SMI the equipment needs to be calibrated. For this set of experiments a manual marker calibration was employed. This procedure involves the experimenter presenting a printed calibration marker in different locations in the visual scene which participants need to follow. Each point of gaze is then automatically registered by the system. This calibration is particularly suited for midrange distances and can accommodate a wide field of view.

Figure 1.2: *Pupil labs head mounted portable eye tracking system*

1.13.2 Recording Motor Phases

The QE definition elaborated by Vickers (1996) stipulates that the QE should be calculated relative to the initiation of specific motor movements and requires the temporal analysis of the different movement phases which were re-coded during the tennis volleying task. To this effect A Go Pro Hero 4 camera was also employed to film tennis performance from an external point of view in all chapters. The recordings were captured at 30 Hz and at a resolution of 720 dpi and employing medium angle of view. Depending on the shot to be executed (forehand of backhand) the camera was set on a tripod which was placed on either side (100cm) and behind (20cm) of where the player stood.

1.13.3 Analysis of Motor and Gaze Data

For all experiments that involved the collection and analysis of video data from the mobile eye tracking glasses and external camera, data were analysed using Quiet Eye Solutions software (www.QuietEyeSolutions.com) which permits the synchronization of the eye-tracking video from the external camera files allowing frame-by-frame coding of the movement phases from the external video in relation to the gaze location and duration from the mobile eye-tracking glasses.

Coding Motor phases**:** The procedure employed to analyse eye tracking data in relation to motor movements is as follows: First, the different motor sequences were individually coded by visualising each sequences for each trial of the tennis volleying task. The tennis task employed five distinct motor phases. The first motor phase was a preparation phase which started from the release of the ball by the feeder (Experiment 3 of Chapter 2) or the ball machine for Chapters 3, 4 and 5. Second the backswing phase began with the first backwards movement of the racket (when the non-dominant hand was on longer holding the racket) and terminated as the racket changed direction at the top of the backswing. Third the fore-swing phase started with the first forward movement of the racket and ended when the racket made contact with the ball the ball. A fourth phase (hitting) was included between contact with the ball and the moment the ball hit the target or surroundings area and a fifth phase between the hit on the target and the moment the ball bounced on the floor signalling the end of each trial. Also these different motor phases and their timings were defined and calculated and in order to compute the QE and other gaze measures, no specific predictions were formulated in terms of potential training effect or the impact of anxiety on these different motor actions.

***Coding eye tracking data*:** The ensuing step in the analysis of gaze data involved coding eye movements in relation to the motor movements captured with the external camera. This was done with the help of the Quiet Eye Solutions software which allows to calculate the length of the QE in relation to specific motor movements. Upon this analysis data can then be downloaded into a Microsoft excel spreadsheet which comprise specific timing info for the QE variable such as QE duration in millisecond, the timing of the onset and offset of the QE for each trial on the tennis task. Information relating to the timing of the different movement phases is also provided for all experiments in which the QE was investigated. Both coding of the motor phases and eye tracking movement was undertaken for all trials across all participants and all conditions (pre training, post training and pressure conditions.

1.13.4 Defining and Calculating the QE for the Tennis Volleying Task

The QE is usually defined as the final fixation or tracking fixation on a location or relevant target within 1 or 3 degree of visual angle, occurring before the initiation of a motor movement and lasting for a minimum of 100ms. Consequently, for the purpose of this thesis and based on previous studies which have previously explored the QE in ball interception sporting tasks (Rodrigues et al., 2002; Wilson et al., 2013) the QE period for the tennis volleying task employed in this thesis was operationally defined as the final tracking gaze on the ball which occurred prior to the initiation of the forward swing of the racquet and lasting until the eyes moved from the ball for more than 1° of visual angle. A tracking gaze was defined as a gaze sustained on the ball within 1° of visual angle for a minimum of 100 ms (Wilson et al., 2013). QE onset was calculated relative to the time of ball release from the machine or the hand of a feeder (in study 3 of chapter 2) and prior to the forward swing of the racquet. QE offset occurred when the gaze deviated off the ball by 1° or more, for 100ms or more. If the cursor disappeared for one or two frames (e.g. a blink) and then returned to the same location, the QE duration resumed. In Experiment 3 of Chapter 1, because the ball was fed by hand a QE measure relative to the flight path of the ball was employed to account for potential for potential variability in the speed of delivery.

1.13.5 Calculating the First Target Fixation for the Tennis Task (FTF)

This index of gaze behaviour was specifically defined for the present research to represent an objective index of 'inhibition' during the volleying tennis task and measure players' ability to 'inhibit' the action of directing their gaze to the target (i.e. checking the outcome of their shots. Specifically FTF reflected the speed at which the target was fixated upon contact of the racket with the ball (the time of first target fixation; FTF). The FTF was therefore operationally defined as the length of time in milliseconds that elapsed between racquet to ball contact and the onset of a fixation on the target which was calculated using the motor phase and eye movements which were analysed for each shot using the Quiet Eye Solution software. Longer durations reflected more efficient inhibition of the target and longer dwell on the ball-racket contact point.

Chapter 2

Can Training Inhibition Improve Cognitive and Motor Task Performance?

2.1 Chapter overview

As it was highlighted in Chapter 1, the ability to perform when confronted with high pressure and anxiety provoking situations is a critical determinant of attainment in sports (Bortoli, Bertollo, Hanin & Robazza, 2012; Nicholls, Holt, Polman & James, 2005). Furthermore, recent developments in the area of sport psychology underline that difficulties in maintaining optimal levels of performance when faced with high-pressure situations are directly related to an athlete's inability to sustain sufficient levels of attention control (e.g. Vine, Lee, Moore & Wilson, 2013; Wilson, Vine & Wood, 2009). These developments emanate from research in the area of cognitive neuroscience investigating the interplay between anxiety and attentional control and their effects on cognitive performance (see Berggren & Derakshan 2013, for a review).

The principal aim of the series of experiments presented in Chapter 2 is to explore if training inhibitory control using an attentional capture task designed to promote the inhibition of distractors in visual search, can also lead to performance benefits in a tennis task performed under pressure. Specifically, experiment 1 will serve to validate the training protocol by determining near transfer effects in a lab based antisaccade task designed to assess inhibitory control. Experiment 2 will pilot the training paradigm in tennis, using a subjective measure of attentional control in tennis and Experiment 3 will investigate the potential benefits of this lab based training paradigm on an objective tennis-specific gaze measure of attentional control and tennis performance on a tennis volley task performed under pressure.

2.2 General Introduction

According to recent models of working memory (e.g. Miyake et al., 2000; Unsworth, Redick, Spillers & Brewer, 2012), attentional control refers to the relative efficiency of the main executive functions of working memory in attaining a task goal. These functions include inhibition (e.g. resistance to distraction), shifting (e.g. within-task control), and updating (e.g. memory-based updating of information). The efficient exercise of working memory functions is thought to play an important role in goal-directed behaviour in general (Duncan & Humphreys, 1989) and sports in particular (Han, Cheong et al., 2014; Furley, Schweizer & Bertrams, 2015). According to the Attentional Control Theory of Anxiety (ACT; Eysenck, Derakshan, Santos & Calvo, 2007) anxious apprehension as well as worrying about performance outcome can disrupt the efficient exercise of attentional control, leading to increased distractibility by task irrelevant stimuli, thus reducing processing efficiency and impaired inhibitory control.

While various accounts of the anxiety-performance relationship exist (e.g. Carson & Collins, 2016; Nieuwenhuys & Oudejans, 2012, 2017), recent research in sport psychology has supported ACT's predictions that deficiencies in the top-down regulation of attention can impair performance in pressurized sporting situations. Specifically, deficits in attentional control tend to result in inefficient processing of the information necessary to plan and execute a skilled movement, as it becomes more difficult to inhibit task irrelevant information (see Wilson, 2012; Eysenck & Wilson, 2016 for recent reviews). For example, Oudejans, Kuijpers, Kooijman and Bakker (2011) discovered that thoughts related to distraction were more common than any other thought category among elite performers in high pressure sporting situations. Furthermore, Englert and Oudejans (2014) demonstrated that reported levels of distraction and an inability to inhibit distracting thoughts mediated the negative effect of anxiety on the performance of tennis players undertaking a serving task.

Additionally, research has revealed that objective measures of optimal goal-directed attention control are sensitive to the effects of pressure. For example, anxiety-related distractibility tends to attenuate the Quiet Eye (QE) period; the duration of the final fixation or tracking gaze to a target initiated prior to a motor movement (Vickers, 1996), which is thought to reflect an index of attentional control in the sports field. Such impairments in inhibitory control have been shown to result in profound decrements in motor performance in various sporting tasks, including golf putting (Vine et al., 2013), basketball free-throw shooting (Wilson et al., 2009), shotgun shooting (Causer, Holmes, Smith & Williams, 2011), archery (Behan & Wilson, 2008), biathlon (Vickers & Williams, 2007), football penalty taking (Wilson, Wood & Vine, 2009), and dart throwing (Nibbeling, Oudejans & Daanen, 2012; Englert, Zwemmer, Bertrams & Oudejans, 2015).

Interventions aimed at training the QE to encourage longer QE periods have been successful in protecting movement outcomes (Causer, Holmes & Williams, 2011; Moore, Vine, Cooke, Ring & Wilson, 2012), perceptions of control (Wood & Wilson, 2012), and muscular and cardiovascular efficiency (Moore et al., 2012) under pressure. It however remains unclear to what extent the beneficial effects of QE training may be due to improved inhibitory control per se (Vine, Moore & Wilson, 2014), as such training methods cannot isolate the specific cognitive mechanisms by which the beneficial effects of training occur. There is therefore a need to explore more direct attentional control training interventions in sport, which can isolate and influence the inhibition function. Additionally, a further advantage of training specific functions of attentional control such as inhibition, as opposed to explicitly encouraging a specific explicit gaze behaviour (e.g. QE), is that training related benefits may transfer to more than one aspect of performance.

The motivation behind the current set of experiments was the promising recent demonstration that attention control can be trained in healthy (Jaeggi, Buschkuehl, Jonides & Shah, 2011) as well as emotionally vulnerable populations affected by anxiety (Sari, Koster, Pourtois & Derakshan, 2016), and depression (e.g. Owens, Koster & Derakshan, 2013), with transferrable gains shown on multiple neural, behavioural, and cognitive outcomes. Similarly, visual search training tasks specifically designed to promote the inhibition of threat-related distractors have been shown to reduce cognitive biases for threat in anxious and depressed populations (Dandeneu & Baldwin, 2004). Capitalising on the above-mentioned promising findings, the current study examined if training the inhibition function component of attentional control, using a visual search training task (based on Theeuwes, 1992), could result in transferrable training-related gains in cognitive and motor performance. The visual search training task required participants to respond to a target stimulus while ignoring a salient task-irrelevant singleton item appearing on half of the trials. While this task has traditionally been employed to examine bottom-up capture of attention, there is strong evidence that the ability to subsequently ignore such salient distractors is dependent on the capacity of attentional control and working memory (e.g. Lavie & de Fockert, 2006; de Fockert & Theeuwes, 2012).

The overall aim of the present set of experiments was to test the efficacy of this tennis specific novel inhibitory control training intervention on far transfer effects on tennis attentional control and performance under pressure. Experiment 1 was designed to validate the training protocol by determining near transfer effects in a cognitive task designed to assess inhibitory control (i.e. antisaccade task; Hallet, 1978). Second, the principal aim of Experiment 2 was to pilot the training paradigm in tennis, using a subjective measure of attentional control specifically developed for tennis (Lafont, 2007, 2008) to assess potential far transfer. Finally, Experiment 3 was conducted to assess the effect of training on an objective tennis-specific gaze measure of attentional control (using mobile eye trackers) and tennis performance measures under competitive pressure.

2.3 *Experiment 1: Training Attentional Control to Improve Inhibitory Control*

2.3.1 Introduction

The antisaccade task is believed to provide a process pure index of inhibition (see Friedman & Miyake, 2004) and has been extensively employed to measure attentional control in diverse populations (see Hutton & Ettinger, 2006; Ettinger, Fiftche, Kumari, Kathmann, Reuter, & Zelaya, 2008, for a review) as well as those suffering from anxiety and depression (e.g. Derakshan, Ansari, Shoker, Hansard, & Eysenck, 2009; Ansari & Derakshan, 2011a, 2011b). The antisaccade task necessitates the efficient suppression of a reflexive saccade towards an abrupt peripheral stimulus and a voluntary shift of attention to its mirror position, implicating the effective exercise of attentional control processes (i.e. the inhibition function) for successful task performance. Antisaccade performance is usually compared to performance on a prosaccade task where the involvement of the inhibition function is removed. During a prosaccade task, participants are exclusively required to saccade towards the abrupt peripheral stimulus, and therefore inhibitory control is not required. Antisaccade latencies and error rates have typically been shown to exceed those of prosaccade latencies and errors (see Hutton & Ettinger, 2006) simply because antisaccade performance involves the efficient exercise of attentional control processes of working memory. It was hypothesized that post-training improvements in antisaccade performance would be greater for the inhibition training group than the control group, as the anti-saccade task is a validated measure of inhibitory control. We in turn expected that training would not modulate prosaccade performance.

2.3.2 Methods

Participants

33 participants were recruited via advertisements placed at the University of London (11 males, 22 females; *M* age = 27.13, *SD* = 4.86). All participants were pseudo- randomly allocated to a control or training group and were naïve to their allocation. Participants had normal or corrected-to-normal vision and wore glasses

or contact lenses if necessary. All participants gave informed consent and were debriefed at the end of the experiment. Ethical permission was obtained prior to study.

Apparatus and stimuli

Training task. The training task (based on Theeuwes, 1992; see Figure 2.1) was a visual search task delivered online using PHP and JavaScript (jQuerry). The search array was preceded by a fixation cross and presented for 800ms. This was followed by a gap interval of 2000ms allowing for responses to be made (press '1' if target present and'2' if target absent). The ten images employed (tennis ball, basketball, dice, golf ball, halved lime, football, lemon, apple, rubber ball, practice golf ball) were sourced online and edited with Adobe Photoshop software. The size of all selected images was reduced to 100x100 pixels and all stimuli were matched for luminosity and brightness. Eight green-yellow images appeared in a circular formation in the visual search array.

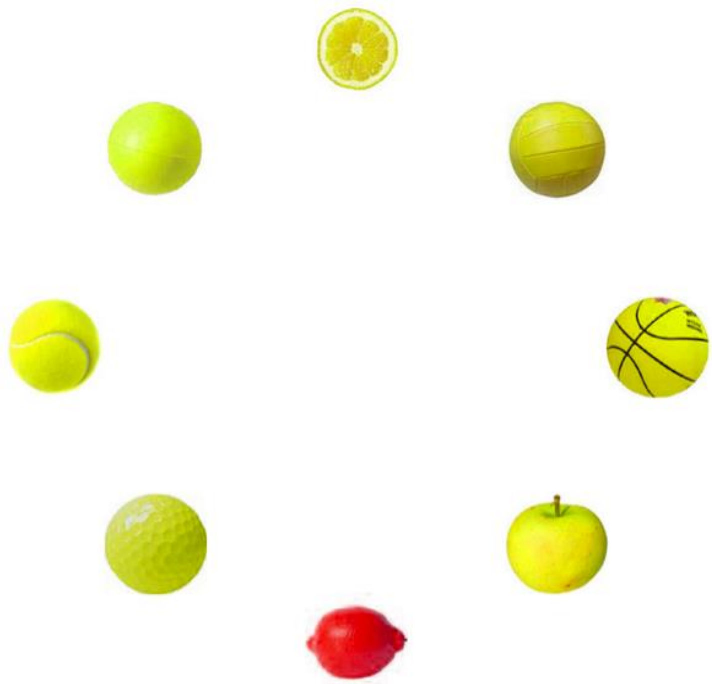


Figure 2.1*: Example of distractor trials from the visual search-training task versions of the array with distractor (red lemon) present and target (yellow tennis ball) present.*

Participants were asked to determine whether the target item (a tennis ball), which appeared on 50% of all trials, was present in the array. For the inhibition training group, a red colour version of one of the non-target items acted as a singleton distractor, and appeared randomly on 50% of the trials. The active control group performed the same visual search task (locating the yellow tennis ball target in the array), but without any red singleton distractors. This control task therefore differed from the training task only in terms of the demands on inhibitory control; a critical requirement when trying to disentangle proposed training benefits in research aiming to examine specific functions of working memory (Shipstead, Harrison & Engle, 2012). The position of the different items in the visual array was randomized for both groups. The task included 4 blocks of 80 trials and lasted about 20 minutes.

Antisaccade and prosaccade tasks (see Figure 2.2). Eye-movements were recorded using an SR Research Eyelink 1000 eye-tracker (SR Research, ON, Canada). Only one eye was tracked during the experiment and nine-point calibration across the computer screen was used to ensure tracking accuracy was within 1° of visual angle. Images were presented on a 21″ Mitsubishi Diamond Pro 2070 CRT monitor (85 Hz) and a chinrest was used to guarantee a constant viewing distance of 60 cm. The experiment was designed and presented using the SR Research Experiment Builder software. The stimulus used for the antisaccade and prosaccade tasks consisted of a white oval-shaped object subtending 2.58° × 4.77° and measuring 35 x 63 mm in dimension which was presented on a black background. This oval shape served as a ‘‘Target’’. Additionally, each trial started with a fixation cross subtending 0.95° × 0.95° and measuring 12 x12 mm presented in the centre of the screen for 1000ms.

Participants were provided with verbal instructions on the anti- and pro-saccade tasks, before undergoing calibration procedures. For each condition, participants undertook 2 blocks of familiarisation comprising 4 trials each. In the antisaccade and prosaccade conditions participants were instructed to fixate the fixation cross until it disappeared. If participants fixated the cross between 500 and 1000ms after its onset, the trial moved forward immediately, acting as a drift correction to tracking. The oval shaped target then appeared with equal probability to the left or right of the fixation cross at 11.04° and for 600ms. Participants were required to direct their gaze, as quickly and as accurately as possible ‘‘TOWARDS’’ the target for prosaccade blocks or ‘‘AWAY’’ from the target and to its mirror image location for antisaccade blocks (see Figure 2.2). The experiment comprised 4 blocks with 2 blocks comprising 35 antisaccade trials and 2 blocks comprising 35 prosaccade trials (cf. Derakshan, Ansari, Shoker, Hansard & Eysenck, 2009). The order of presentation of anti-saccade and pro-saccade blocks was counterbalanced across participants and groups for pre- and post-intervention testing sessions.

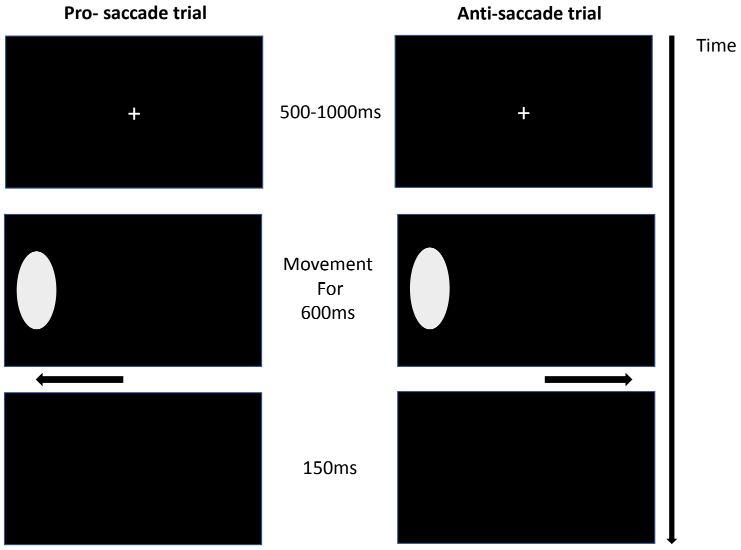


Figure 2.1: *An example of a Pro-saccade trial and an Anti-saccade trial.*

Procedure

The design followed a pre-test, intervention, and post-test format. Pre- and post-testing sessions each lasted for approximately 25 minutes and took place in a sound-protected and dimly lit sound-proofed testing cubicle. Upon arriving for the pre-testing session, participants first completed a consent form and the STAI state and trait anxiety questionnaires (Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983), before completing the antisaccade/prosaccade tasks. The experimenter matched participants on pre-test measures of trait anxiety (Control M = 38.66, SD = 10.93; Training M = 42.68, SD = 11.51) and age (Control M = 25.67, SD = 4.49; Training M = 29.19, SD = 5.3), before pseudo-randomly allocating them to active control or inhibition training groups, and demonstrating the relevant training task.

Participants were sent a designated web link via e-mail to access the training task at home. The intervention required participant to undertake training online on the visual search task for 6 consecutive days. Participants were instructed to create a quiet environment in order to avoid potential distractions and undertook the task at approximately the same time every day, with their performance being monitored remotely by the experimenter. Upon completing the post-test pro- and antisaccade tasks, participants were debriefed, thanked and remunerated £20 for their participation.

Data Analysis

A General Linear Model Mixed design ANOVA with Group (Training, Control), Task (Antisaccade, Prosaccade) and Time (Pre, Post intervention) as factors was performed on response latencies using SPSS (version 21) software.

2.2.4 Results

Manipulation Check: Training Task

One participant in the control group dropped out during the training phase of the experiment and one participant in the training group was excluded from the study due to poor performance on the pro/anti-saccade tasks (less than 50% accuracy), leaving a final sample of 31 participants. For the training group, the extent of performance improvement as indicated by the reduction of distractor costs in the visual training task was calculated by subtracting reaction times on target-present trials without a distractor from reaction times on trials with a distractor. The ability to inhibit distractors when identifying targets in the visual search task gradually improved across the period of training, as indicated by a t-test that showed that distractor costs towards the end of training (i.e. Days 5 and 6: M = -15.85, SE =

6.44) were significantly lower than distractor costs at the beginning of the training (i.e. Days 1 and 2: M = 2.99, SE = 7.90), $t(15) = 2.18$, $p = .04$.

Antisaccade and Prosaccade Task Performance

Latencies. Only response latencies for accurate trials in both the antisaccade and prosaccade conditions are reported. The data of one participant in the training group were removed from the final analysis due to being higher than 3SDs of the average performance. Thus, data for 30 participants (15 in each group) were used in the analysis. Trials with saccadic latencies below 83ms (less than 3% of the data: 1.3% for training and 1.25% for control) were considered anticipatory (see Fischer et al., 1993) and together with trials where no saccade was made (less than 1.3%) were excluded from the analysis.

The ANOVA revealed significant main effects for Time; $F(1, 28) = 9.88$, $p = .004$, $\eta^2_p = .26$, and Task; $F(1, 28) = 123.63$, $p = .001$, $\eta^2_p = .81$, but not Group; $F(1, 28) = 2.20$, $p = .14$. Performance improved from pre- (M = 227.79ms, SD = 30.74) to post- (M = 217.77ms, SD = 33.18) intervention. The main effect of Task showed that antisaccade latencies (M = 253.50ms, SD = 35.54) were generally slower compared with the prosaccade (M = 195.50ms, SD = 30.74) task. The lack of a main effect of Group showed that the groups did not differ from each other on saccadic latencies (Training: M = 229.79, SD = 31.28; Control: M = 215.77, SD = 18.92). The two-way interactions of Task X Group, $F(1, 28) < 1$, and Time X Group, $F(1, 28) = 2.82$, $p = .10$, were also not significant. There was a trend for the Group X Task interaction to be significant, $F(1, 28) = 3.57$, $p = .06$, which was qualified by a trend for the hypothesized 3-way Time X Group X Task interaction;

$F(1, 28) = 3.16$, $p = .08$, $\eta^2_p = .10$. Because of its direct relevance to the main predictions of the study, the three way interaction was followed up by relevant t-tests that showed that the improvement over time was driven primarily by the training group's significant decrease in response latency in the antisaccade task (Pre-intervention $M = 258.82$, SD = 35.41; Post-intervention: $M = 235.49$, $SD = 32.02$) ; $t(14) = 3.78$, $p = .002$, compared to the control group who revealed no significant improvement in anti-saccade task performance (Pre-intervention $M = 262.31$, $SD = 35.78$; Post-intervention $M = 257.41$, $SD = 37.56$) $t(14) = 0.73$, $p = .47$ (see Figure 2.3). For the prosaccade task, there were no significant pre- to post-changes in response latency for either the training group: $t(14) = 1.50$, $p = .15$ or the control group; $t(14) = 1.25$, $p = .23$ (see Figure 2.4).

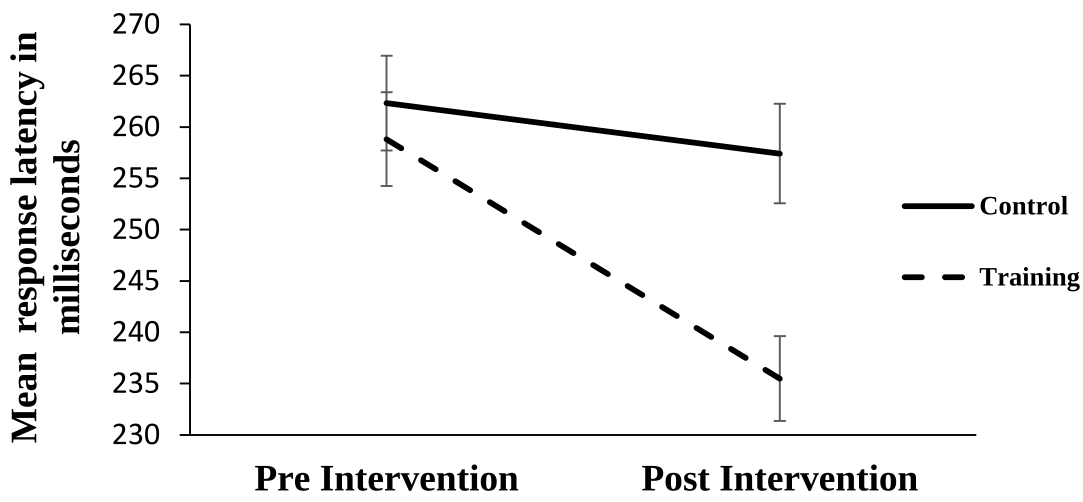


Figure 2.3:*Mean Antisaccade latencies (in milliseconds) for training and control groups (Error bars=MSE).*

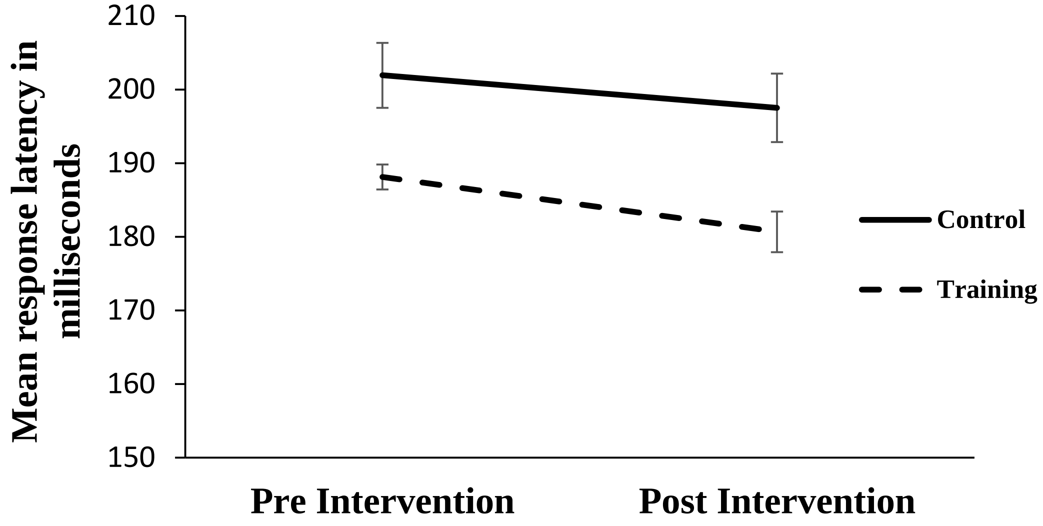


Figure 2.4: *Mean Prosaccade latencies (in milliseconds) for training and control groups (Error bars=MSE).*

Error rates. Anti-saccade error rates at pre-intervention (*M* = 12.5, *SD* = 2.29) were comparable to those at post-intervention (*M* = 12.26, *SD* = 10.25). A similar pattern was observed with pro-saccades where error rates at pre-intervention (*M* = 2.06, *SD* = 2.29) were comparable to those at post-intervention (*M* = 1.66, *SD* = 2.04), $t(29) = 6.69$, $p < .001$. A 2 (Group: Training, Control) X 2 (Time: Pre-intervention, Post-intervention) on anti-saccade error rates did not find a main effect of Time or an interaction of Time X Group (both *F*s < 1). The same analysis on pro-saccade error rates also failed to find a significant main effect of Time $F(1, 28) = 2.46$ $p = .128$, Group F $(1, 28) = 2.72$ $p = .110$, and the interaction between Time X Group was not significant F $(1, 28) = 2.46$ $p = .128$.

2.3.4 Discussion

The aim of Experiment 1 was to investigate whether training on a visual search task designed to promote distractor inhibition would provide near transfer to antisaccade task performance; considered to provide a robust measure of inhibition and resistance to distraction (Friedman & Miyake, 2004; Derakshan et al., 2009). Results showed that participants allocated to the training group significantly reduced their response latencies for the antisaccade task after the intervention, whereas the control group remained at pre-test levels. Neither group significantly improved their prosaccade performance. While training resulted in faster anti-saccade latencies, it did not reduce error rates, perhaps due to the finding that error rates were close to baseline at pre-test for both groups. Increased correct anti-saccade latencies have usually been taken to index deficits in processing efficiency and attentional control (see Fox, Derakshan & Standage, 2011, for a review) and are thought to reflect the recruitment of additional processing resources used towards the inhibition of reflexive pro-saccades (Olk & Kingstone, 2003).

These findings provide strong support that the underlying mechanisms of near transfer are related to improved inhibition. Specifically, inhibition training enabled a greater ability to inhibit task-irrelevant distracting information when needed, something that the active control group (despite performing the same visual search training task) was unable to do. Interpretations surrounding the reliability of transfer related gains on response time latencies, in training designs lacking an active control group, have been raised elsewhere (see Engle et al., 2014). The design of the current paradigm overcomes this potential problem with the inclusion of an active control group.

2.4 *Experiment 2: The Impact of Inhibitory Control Training on Attentional Control in Tennis*

2.4.1 Introduction

The results of Experiment 1 provide direct evidence for the effectiveness of the training task in targeting inhibitory control as measured by antisaccade task performance. Effective top down attentional control, and the inhibition of irrelevant distractions, is also important in the planning and control of goal-directed motor responses (Corbetta & Shulman, 2002) and for efficient sports performance (Kao, Huang & Hung, 2015; Chuang, Huang & Hung, 2013). For example, Kasper, Elliott and Giesbrecht (2012) found that putting accuracy of novice golfers was strongly related with the efficiency of the inhibition function. An initial field tennis experiment was therefore conducted to test the potential effectiveness of this form of attentional control training in a sample of recreational tennis players undertaking a series of returns of serve. Return of tennis serve was chosen as a relevant transfer task, due to the important attentional demands involved in optimizing efficient motor preparation and control within a constrained time period (e.g. Williams, Ward, Smeeton & Allen, 2004).

Attentional control was assessed via expert ratings of the players' behaviours, determined from video footage. This method was taken from previous research in tennis by Lafont (2007, 2008) who, following a detailed photo analysis, observed that elite tennis players usually show a characteristic head fixation toward the area of contact with the ball from the time of impact and through the early phase of the follow through. More specifically, not only did Lafont (2007, 2008) observe that tennis players tend to fixate on the ball-racquet contact area at the time of the hit, but this gaze also remained steady even after the contact point, when the ball was already on its way towards the opponent. Lafont (2007, 2008) consequently argued that this measure of visual attentional control – resembling the late portion of the QE – is indicative of superior tennis performance. This is also consistent with previous research in golf (Vine et al., 2013), which demonstrated that unsuccessful putts generally resulted from a shorter fixation on the ball at the time of impact and an earlier attempt to fixate the hole (i.e. impaired inhibition). Specifically, the present experiment assessed the orientation of the players' eyes or head (i.e. gaze) on the ball during and following contact with the racquet. We hypothesized that participants in the training group would reveal superior post-training visual attentional control, compared to their control group counterparts.

2.4.2 Methods

Participants

Participants were recruited from an opportunity sample of recreational tennis players who engage in tennis activities between 1 and 3 times per week at the Highbury Field Tennis Club and at the Islington Tennis Centre, London, UK. The sample included 26 participants (11 males, 15 females; *M* age = 49 years, *SD* = 6.66). Participants gave informed consent and were debriefed at the end of the experiment. Ethical permission was obtained prior to the study.

Materials and Stimuli

Training task. The training task was the same attentional capture task employed in Experiment 1, delivered online using PHP and JavaScript (jQuerry).

Tennis field task. There were two tennis testing sessions where standard tennis racquets and 24 new tennis balls were used. All testing sessions took place on an indoor tennis court at the Islington Tennis Centre. Participants attempted to return all serves from the same side of the court for both pre- and post-tests sessions. A tablet computer with a capture rate of 30Hz was used to record participants' tennis performance in detail. The tablet stood on the side of the returner just outside the double side-line levelled with the service line. All shots were recorded individually and captured a full view of the player. During the tennis test, participants were required to return 16 tennis serves delivered by two experienced level 4 LTA licensed tennis coaches who were blind to participants' group allocation. The server ensured that the difficulty of the serves to be returned were appropriate to the participants' skill level (as assessed during pilot testing). All serves that landed out were retaken and participants received an equal number of serves to the right and the left of their body with the server serving to a different location in a pseudo-random order for all participants. Participants were instructed to stand behind the baseline and to return the ball inside the court for each serve as they would in a regular game of tennis. The two tennis coaches served to the same participants in pre- and post- tennis tests.

All returns were later viewed in slow motion via Quick Time (Apple) and the orientation of the players' eyes or head (i.e. gaze) on the ball during and following contact with the racquet, was rated independently by two qualified LTA level 4 tennis coaches (one of whom was blind to training group allocation) on a scale of 1 to 5. A score of 1 reflected excellent attentional control (with gaze being maintained prior to, during and after racquet-ball contact) and 5 reflected very poor attentional control (no or limited focus on the ball preceding, or during racquet-ball contact).

Procedure

The design of the experiment followed a pre-test, intervention, post-test format. Participants were told that the study was investigating ‘anxiety and attention in tennis’ and were randomly allocated to the training and control groups. Participants were naïve to their group allocation and were matched as closely as possible on pre-test measures of trait anxiety (STAI: Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983), Control M = 34.25, SD = 7.86; Training M = 35.25, SD = 8.02), age (Control M = 50.25, SD = 6.00; Training M = 46.75, SD = 7.08) and tennis ability as assessed by the tennis experts during warm-up sessions. At pre-test all participants performed the return of serve task. The training paradigm followed the same procedures as in Experiment 1. At post-test, participants were assessed on the tennis test in the same format as at pre-test. Participants were then thanked for their participation and offered a free future tennis class as remuneration.

Data Analysis

2 x 2 mixed design ANOVA with Group (Training and Control) and Time (Pre- and Post- Intervention) as factors were computed for coach ratings in SPSS.

2.4.3 Results

***Manipulation Check: Training Task*.** One participant in each of the training and control groups dropped out during the training phase leaving a final sample of 24 participants. Distractor costs (see Experiment 1) towards the end of the training phase (i.e. Days 5 and 6: M = -4.21, SE = 7.61) were significantly lower than distractor costs at the beginning of training (i.e. Days 1 and 2: M = 53.38, SE = 26.27), $t(11) = 2.23$, $p = .04$. This finding indicated that training improved the inhibition of distractors in the visual search task across the six days of training.

Reliability Analysis. A reliability analysis was conducted on the ratings of the 2 independent raters for pre and post intervention ratings. These appeared to have acceptable internal consistency for both the pre ($\alpha = .72$) and post ($\alpha = .75$) intervention periods (Kline, 2000).

Tennis Attentional Control Ratings ANOVA revealed a significant main effect of Time, $F(1, 22) = 11.30$, $p = .003$, $\eta^2_p = .34$, but not Group; $F < 1$. A significant Time X Group interaction, $F(1, 22) = 4.55$, $p = .04$, $\eta^2_p = .18$, revealed that significant training-related gains in attentional control occurred from pre (M = 2.62, SD = .46) to post intervention (M = 2.31, SD = .25) for the training group, $t(11) = 4.00$, $p = .002$, but not the control group (Pre M = 2.62, SD = .79 ; Post M = 2.53, SD = .57), $t < 1$ (see Figure 2.5).

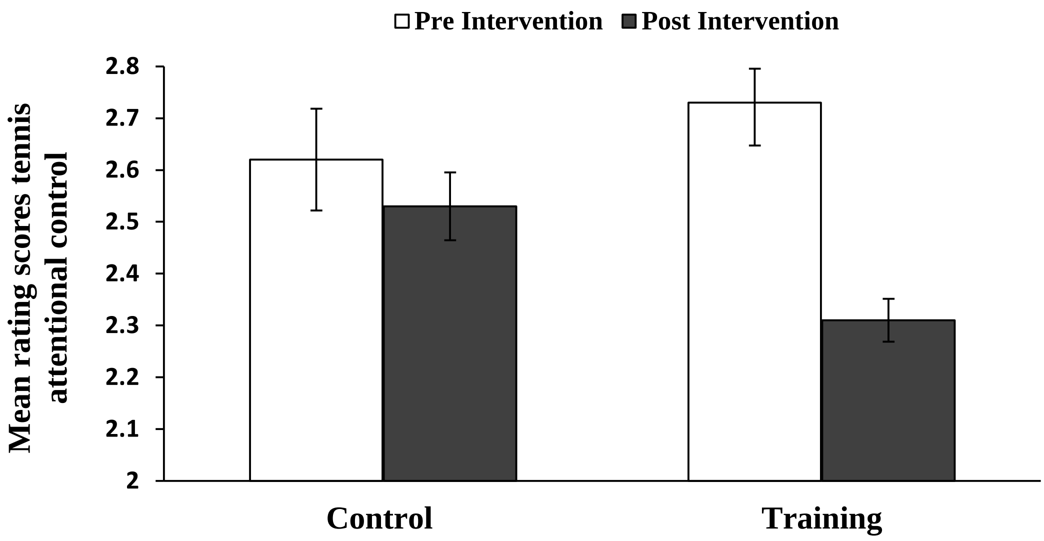


Figure 2.5: *Mean tennis attentional control ratings for training and control group (Error bars = SEM).*

2.4.4 Discussion

Experiment 2 was designed to investigate if the novel inhibition training task designed for the present set of studies would lead to improvements in task specific attention control in recreational tennis players, as assessed by coach ratings of their gaze orientation during and beyond racquet-ball contact. As such, its main aim was to examine if the near transfer effects found in Experiment 1 could be replicated and extended to a sporting task; thus further supporting the utility of exploring generalized inhibitory control training for real-world tasks (Kao et al., 2015; Chuang et al., 2013; Kasper et al., 2012). The independent ratings demonstrated that a critical component of attention control when hitting a tennis ball (Lafont, 2007, 2008) was significantly improved after the training intervention compared with the control group whose performance did not improve. When interpreted together with the findings from the anti and prosaccade tasks in Experiment 1, these transfer effects appear to be driven by improved efficiency of the inhibition function. The results suggest that such training has a generalized effect; supporting task performance irrespective of the source of task-specific distraction, or the response mode. The ability to provide clearer mechanisms of focus is a significant advance on previous paradigms adopting quiet eye training (e.g. Causer et al., 2011b; Moore et al., 2012a), where the beneficial performance effects found may or may not reflect enhanced ability to resist distraction (the inhibition function).

While providing promising initial support for the transferability of the attentional control training paradigm to a motor task, the measure of gaze control was relatively crude (cf. Experiment 1), and no measure of performance for the return of serve was taken. Additionally, the rationale for training inhibition in sporting tasks was primarily due to its potential in modulating the influence of competitive pressure on performance (Englert & Oudejans, 2014; Oudejans et al., 2011), yet no pressure manipulation was included in Experiment 2. Experiment 3 was designed to address both these limitations.

2.5 *Experiment 3: Training Attentional Control to Improve Performance and Gaze Indices of Attentional Control During a Tennis Volleying Task*

2.5.1 Introduction

Encouraging transfer effects of inhibition training were observed on a lab based measure of inhibitory control and gaze behaviour (Experiment 1) and on independent ratings of attentional control in the field (Experiment 2) during a return of serve live task. However, a stronger test of the utility of the training paradigm requires the measurement of relevant and objective measures of attentional control and performance in tennis. Additionally, potential detrimental effects of anxiety on performance and any protective influence of the visual search training paradigm need to be assessed, given the theoretical (e.g. ACT; Eysenck et al., 2007) and empirical (e.g. QE attenuation under pressure; Vine et al., 2013) backdrop to the research.

As such Experiment 3 employed a tennis volleying task, where participants were required to hit a thrown tennis ball to a circular (archery) target. This task allowed an objective measure of tennis performance to be obtained whilst gaze behaviours were recorded. As outlined in the introduction, previous research has demonstrated that objective gaze measures of visual attention (e.g. QE) during the performance of motor tasks are susceptible to pressure. For example, Vine et al. (2013) revealed that when skilled golfers missed a putt during a competitive shootout, this failure was accompanied by a shorter final aiming fixation on the ball (QE) and an earlier attempt to fixate the hole (i.e. impaired inhibition), compared to successful attempts. The authors postulated that apprehension about performance outcome makes it harder to inhibit the desire to direct gaze towards the hole in order to validate the outcome of their attempts, rather than maintain goal-directed focus on ensuring a good contact between putter and ball. Training the maintenance of goal-directed attention (QE training) has been shown to insulate against outcome-focused distraction and protect performance under pressure (e.g. Vine et al., 2011). Similar impairments in inhibition during a far aiming task have been found in football penalty taking (e.g. Wilson, Wood, & Vine, 2009; Wood & Wilson, 2010) when anxious penalty takers find it harder to inhibit the threatening goalkeeper. In both tasks, training the maintenance of goal-directed attention (QE training) has been shown to insulate against these forms of distraction and protect performance under pressure (e.g. Vine et al., 2011; Wood & Wilson, 2011).

While the tennis volley task involves a similar ball striking element as golf putting and football penalties, there is also an interceptive element; the performer needs to time his/her shot relative to the flight characteristics of the incoming ball. Task relevant gaze tracking periods have been found to discriminate between successful and unsuccessful performance in a range of interception tasks; including ball catching task (Wilson, Miles, Vine &Vickers, 2013), volleyball return (Vickers & Adolphe, 1997), hockey goal tending (Panchuk & Vickers, 2006) and shotgun shooting (Causer et al., 2010). In interceptive tasks, better performance is underpinned by an earlier onset and longer duration of pursuit tracking prior to the interception attempt (see Wilson et al., 2015 for a review). The earlier and longer tracking gaze is thought to provide a sufficient period of cognitive processing during which the control parameters of the ensuing motor skill are programmed (Vickers, 1996). In the only study conducted to examine the influence of competitive pressure on skilled performance and QE in an interception task, Causer et al. (2011) found that both the QE duration (time spent tracking the clay prior to trigger pull) and the performance of elite shotgun shooters was significantly reduced under a competitive condition compared to a training (control) condition.

The principal aim of Experiment 3 was to examine if the novel inhibition training paradigm could reveal similar benefits to sport skill performance as previously found for QE training. In tennis, it is important to maintain attentional focus on the hit zone during and beyond racquet-ball contact to ensure accuracy (Lafont, 2007, 2008), and it was shown in Experiment 2 that this strategy reflects efficient inhibition control. Based on the predictions of ACT (Eysenck et al., 2007; Eysenck & Wilson, 2016) and the findings of Vine et al. (2013) in golf putting, it was first hypothesized that pressure would disrupt the efficiency of the inhibition function; tennis players would not maintain a goal-directed focus on the hit point, but would rather direct an earlier fixation to the scoring target. However, we also hypothesized that inhibition training would modulate this effect: the trained participants would maintain their focus on the impact area (racquet and ball) and have later fixations to the target under pressure compared to the control participants. Lastly we also predicted that those allocated to the training group would display longer tracking gaze on the approaching ball (i.e. the QE in tennis) following training.

2.5.2 Methods

Participants

An opportunity sample of 22 recreational tennis players who usually engage in tennis activities between 1 and 3 times per week were recruited via advertisements placed at the University of Exeter and around Exeter local tennis clubs (11 males, 11 females; 2 left handed, 20 right handed; *M* age = 27.84, *SD* = 5.63). Participants had normal or corrected-to-normal vision and wore contact lenses if necessary. All participants gave informed consent and were debriefed upon completing the final tests. Ethical approval was obtained prior to the conduction of the study.

Materials and stimuli

Training task. The training task was the same attentional capture task employed in Experiments 1 and 2, delivered online using PHP and JavaScript (jQuerry).

Tennis task. A volleying task (see Figure 2.6) was designed, to enable performance accuracy to be assessed whilst gaze could be recorded. The tennis volley is one of the most technically difficult shots to execute and since it is mostly used to conclude a point (cf. rallying groundstrokes or service return) it can be prone to break down under pressure (Roetert & Groppel, 2001). Participants were required to execute a series of volleys as accurately as possible into a target area (a 120cm x 120cm FITA approved archery target) placed on a blank wall at a distance of 460cm from the player and 100cm from the floor. This distance was determined as it mimics on-court conditions for volleying, and when compared to other distances used in pilot testing, it revealed a consistent ratio between misses and hits (minimizing possible ceiling and floor effects). The task comprised 20 trials, divided into 2 blocks of 5 forehands and 2 blocks of 5 backhands. A set of 20 Dunlop Fort All Courts balls and a Babolat Pure Drive tennis racket were employed for the duration of the study. The feeder stood at a distance of 70 cm laterally to the left or right of the target, for forehand and backhand volleys respectively. The position of the feeder was reversed for left handed players. The feeder threw the ball in an underhand motion, and aimed to keep the speed of the delivery constant across trials . Participants were instructed to aim for the centre of the archery target on every shot.

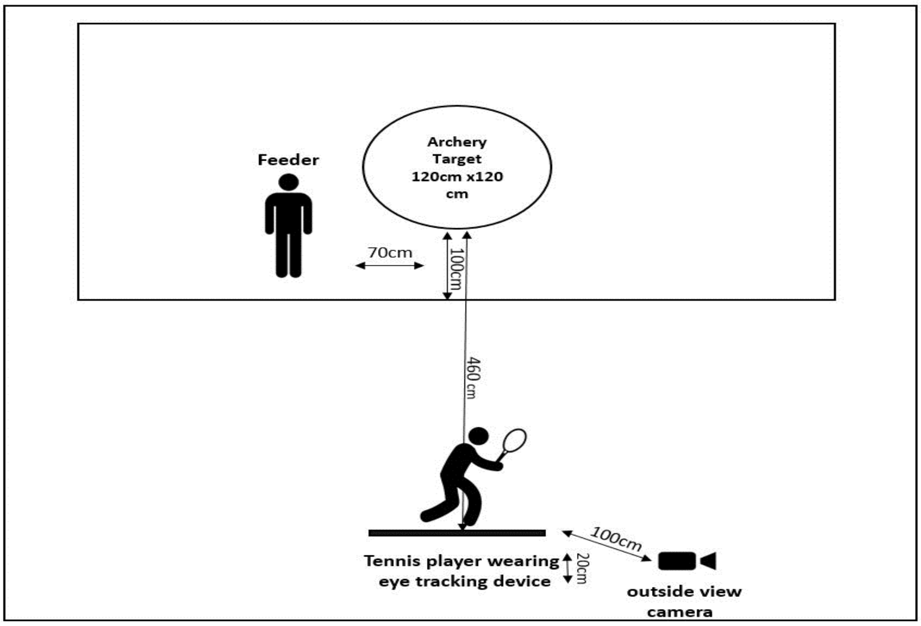


Figure 2.6: *Example of trial on the tennis volleying task.*

Measures

State anxiety. Cognitive state anxiety was assessed at 3 time points; before the first block of 5 shots, after the second block (midway), and after the fourth block (at the end), using the Mental Readiness Form (MFR-3; Krane 1994). The MRF-3 comprises 3 bipolar 11-point Likert scales that are anchored between ‘not worried – worried’ for the cognitive anxiety scale; ‘not tense – tense’ for the somatic anxiety scale; and ‘not confident – confident’ for the self-confidence scale. The cognitive anxiety subscale has been frequently employed by researchers seeking to assess the experience of competitive sporting pressure (e.g. Vine et al., 2011; Wilson et al., 2009). A mean value across the three time points was used for subsequent analyses.

Tennis field performance. Tennis performance was assessed in terms of shot accuracy and errors made on the volleying task. Accuracy scores were obtained by determining where the ball landed within the scoring rings on the archery target, from post-test analysis of the video footage. Error percentage was calculated as the percentage of shots that missed the target area. Such 'misses' reflect poor performance (e.g. Vickers, 1996) and are more likely to occur under competitive pressure (Vine et al., 2013).

Gaze measures and video data Gaze SensoMotoric Instrument' (SMI ETG) Mobile Eye Tracking glasses were used to measure and record momentary gaze (at 30 Hz). The resolution of the scene camera was 1024x720p at 30 fps. A circular cursor (representing 1° of visual angle) indicating the location of gaze in a video image of the scene (spatial accuracy of ± 0.5° visual angle; 0.1° precision) was recorded for offline analysis. Gaze data were analysed in a frame-by-frame manner using Quiet Eye Solutions software (www.QuietEyeSolutions.com) (See method section of General discussion).

First target fixation (FTF). FTF was defined for the present study to represent an objective measure of 'inhibition' during the volleying tennis task. Instead of calculating the attenuation of gaze period on a stationary object (cf. Vine et al., 2013 in golf putting), its corollary was calculated: the speed at which the target was fixated (the time of first target fixation; FTF). Specifically, the FTF was operationally defined as the length of time in milliseconds that elapsed between racquet to ball contact and the onset of a fixation on the target. Longer durations therefore reflect an optimal strategy similar to that identified by Lafont (2007, 2008) and more efficient inhibition of the target (cf. antisaccade performance; Experiment 1).

Quiet eye (QE) period. Based on previous research investing the QE in an interception task (Wilson et al., 2013) the tennis volleying task was operationally defined as the final tracking fixation on the ball prior to the initiation of the forward swing of the racquet. A tracking fixation was defined as a gaze sustained on the ball within 1° of visual angle for a minimum of 100 ms (Wilson et al., 2013). QE onset occurred before the tennis player started the forward swing of the racquet and QE offset occurred when the gaze deviated off the fixated location (ball) by 1° or more, for greater than 100 ms. If the cursor disappeared for one or two frames (e.g. a blink) and then returned to the same location, the QE duration resumed. As in previous research exploring the QE when tracking a ball (e.g. Miles et al., 2015) a relative QE period was calculated to reflect potential differences in ball fight time. Relative QE (Rel QE) was calculated as a percentage of the ball flight time for that trial.

Phase Durations. The durations of the phases of the tennis volley were calculated using Quiet Eye Solutions software (Quiet Eye Solutions Inc., Calgary, CA). The preparation phase started 2.5 seconds prior to when the ball made contact with the racket and lasted until the release of the ball by the feeder. The backswing phase began with the first backwards movement of the racket and terminated as the racket changed direction at the top of the backswing. The fore-swing phase started with the first forward movement of the racket and ended when the racket made contact with the ball the ball. A fourth phase (hitting) was included between contact with the ball and the moment the ball hit the target or surroundings area and a fifth phase between the hit on the wall and the moment the ball landed on the floor signalling the end of each trial.

Procedure

The design of the experiment followed a pre-test, intervention, post-test format. Participants were initially matched on pre-test measures of trait anxiety (STAI: Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983) (Control M = 33.36, SD = 5.23; Training M = 33.90, SD = 7.21), age (Control M = 22.09, SD = 8.68; Training M = 24.81, SD = 13.54) and tennis performance (i.e. error rates) (Control M = 40.00 %, SD = 19.36; Training M = 41.81%, SD = 14.19) and pseudo-randomly allocated to a control or a training group. At pre intervention, participants were initially given brief instructions on how to proceed with the online home training task (identical to Experiments 1 and 2) and undertook a short practice on the tennis task. The eye-tracking equipment was then fitted and calibrated using a 3-point calibration procedure. Lastly participants were asked to complete the MRF-3.

Participants were required to volley a tennis ball, which was hand fed by a tennis coach, onto an archery target placed onto a blank wall. Participants were instructed to stand with both feet on a designated line whilst keeping a steady ready position holding their racquet with both hands around waist height. The task comprised of 20 trials, divided into 2 blocks of 5 forehands and 2 blocks of 5 backhands and lasted around 5 minutes. Upon finishing the first 2 blocks consisting of 5 forehands and 5 backhand volleys, participants were required to complete the MRF-3, which was completed again at the end of the whole task.

In the post-training session, participants initially completed the same procedures as in the pre-training session. However, they were then instructed to repeat the tennis task in a pressurized condition. As in previous research interested in the effect of pressure on sports performance (e.g. Wilson et al., 2009; Vine et al., 2011) a variety of approaches were employed to increase cognitive anxiety. First of all, participants were told that their data may be used in a proposed sports science TV program and that their performance would be evaluated by tennis experts against the performance of other participants taking part in the study (a mock consent form which included TV branding was completed). Participants were also told that the tennis experts would analyse their facial expression during the task. Lastly they were informed that a ranking system based on their tennis scores had been put in place. Non-contingent feedback was given, with participants being told that their scores from the previous 20 volleys in the post-test tennis task would put them in the bottom 30% when compared to participants who had already completed the study. They were encouraged to try and improve upon their performance and told that otherwise their data could not be used. Upon completing the pressure condition tennis task participants were debriefed about the study's aims and thanked for their participation. Participants were compensated with £20 pounds for around three and a half experimental hours.

Data Analysis

As there were no group differences between any of our dependent variables at pre-test[1] we focus our analysis on the post training conditions (Low pressure vs. High pressure). Dependent variables were therefore subjected to 2 x 2 Group (Control vs. Training) x Condition (Low vs. High pressure) mixed analyses of variance. Linear regressions were also conducted to assess whether FTF and the QE predicted tennis performance (aggregated across both Low and High pressure testing sessions).

2.5.4 Results

Training Task Manipulation Check. As in Experiments 1 and 2, the ability to inhibit distractors when identifying targets in the visual search task gradually improved across the period of training, as indicated by a t-test that showed that distractor costs towards the end of training (i.e. Days 4, 5 and 6; M = .53, SD = 8.17) were significantly lower; $t(10) = 3.02$, p = .013, than distractor costs at the beginning of the training (i.e. Days 1, 2 and 3; M = 7.52, SD = 11.55).

Cognitive Anxiety. ANOVA revealed a significant main effect of Condition, $F(1, 20) = 15.40$, p = .001, η^2_p = .43, with participants reporting significantly higher levels of cognitive anxiety in the high pressure(M = 4.19, SD = 2.09) as opposed to low-pressure session (M = 2.96, SD = 1.83), indicating that the pressure manipulation was successful. There was no main effect of Group, and no Condition X Group interaction *(Fs* < 1), reflecting that both groups had similar reactions to the pressure manipulation.

Tennis Performance (errors). ANOVA revealed no significant main effect of Condition, $F(1, 20) = 2.41$, $p = .13$, $\eta^2_p = .11$, or Group; $F < 1$. However, there was a Condition X Group interaction, $F(1, 20) = 4.74$, $p = .04$, $\eta^2_p = .19$. This interaction was driven by a significant decrease in the percentage of errors made by the training group $t(10) = 3.068$, $p = .002$ (Low pressure $M = 39.09\%$, $SD = 11.79$; High pressure $M = 28.18\%$, $SD = 15.53$), compared to the control group who revealed no significant improvement between the two testing sessions, (Low pressure $M = 40.45\%$, $SD = 19.93$; High pressure $M = 42, 27\%$, $SD = 16.33$), $t < 1$. The main effect of Group was not significant $F < 1$.

Tennis Performance (Accuracy). A 2x2 mixed ANOVA with Group (Training, Control) and Condition (low pressure, high pressure) revealed a significant main effect of Condition, $F(1, 20) = 8.824$, $p = .008$, $\eta^2 p = .306$, showing that performance improved from pre ($M = 2.67$, $SD = .94$) to post ($M = 3.19$, $SD = 1.04$) intervention. There was no Condition X Group interaction, 2.14, $p = .158$, $\eta^2 p = .097$ or a main effect of group $F < 1$. (see table 2.1)

First Target Fixation (FTF). 8.7% of trials across testing sessions were lost due to calibration errors or no eye-movements to the target at the time of contact with the ball. Ten percent of the FTF data were analysed by a second independent rater who was blind to both the aims of the experiment and participants' group allocation. Results revealed high levels of agreement between the two raters, $r = .97$, $p < .001$, confirming the reliability of the coding process (Vine et al., 2011).

The main effect of Group was not significant $F < 1$. However, ANOVA revealed a significant main effect of Condition, $F(1, 19) = 8.65$, $p = .008$, $\eta^2_p = .30$, indicating a general reduction in the length of FTF from the low pressure (*M* = 106.63ms, *SD* = 134.63) to the high pressure session (*M* = 81.63ms, *SD* = 107.15). This was qualified by a significant Condition X Group interaction, $F(1, 19) = 8.17$, $p = .01$, $\eta^2_p = .30$. Further analyses indicated that this interaction was driven by significant reductions in the length of FTF for the control group $t(10) = 3.550$, $p = .005$ (Low pressure *M* = 106.63ms, *SD* = 134.63; High pressure: *M* = 69.01 ms, *SD* = 115.64), compared to the training group who showed no significant reduction in the length of FTF between the two testing sessions: (Low pressure *M* = 96.18ms, *SD* = 96.63; High pressure *M* = 95.50ms, *SD* = 101.23) $t < 1$ (see Table 2.1).

Relative QE period (RE QE). 5.6 % of trials across all testing sessions and participants could not be analysed due to gaze not being registered. Table 2 shows performance improvements in terms of gaze behaviours (i.e. the QE and FTF).. A 2x2 mixed ANOVA with Group (Training, Control) and Condition(Post, pressure intervention) revealed a significant main effect of Condition, F (1, 20) = 7.657, $p = .012$, $\eta^2 p = .108$ indicating that RE QE durations were generally longer in the High pressure (*M* = 74.51%, *SD* = 6.38) session than in the initial Low pressure session (*M*= 70.94%, *SD*= 6.56) Nevertheless there was no significant Condition X Group interaction nor a main effect of Group $F < 1$.

Footnote

[1] Tennis error performance in the pre testing session (% misses) was similar ($t < 1$) for both control (*M* = 40.00 %, *SD* = 19.36) and training (*M* = 41.81 %, *SD* = 14.19) group. Tennis accuracy performance in the pre testing session was similar ($t < 1$) for both control (*M* = 2.75, *SD* = 1.15) and training (*M* = 2.59, *SD* = .70) group. First Target Fixation (FTF) was also comparable ($t < 1$)

for both control (M = 90.73ms, SD = 124.96) and training (M = 113.33ms, SD = 105.29) group. In the pre testing session relative QE durations were comparable for both control (M = 67.71%, SD = 4.03) and training group (M = 64.59%, SD = 2.07) $t < 1$.

Table 2.1: *Mean tennis performance sand gaze behaviours scores with standard deviations (in parentheses).*

		Tennis Performance		**Gaze Performance**	
Condition	Group	Accuracy	Error (%)	RE QE (%)	FTF(ms)
No pressure	Training	2.43 (1.06)	39.09 (11.79)	70.58 (4.44)	96.18 (96.63)
Pressure	Training	3.01 (1.05)	28.18 (15.53)	74.47 (5.7)	95.50 (101.23)
No pressure	Control	2.58 (.89)	40.45 (19.93)	70.38 (8.5)	106.63 (134.6)
Pressure	Control	3.36 (1.05)	42.27 (16.33)	74.47 (7.1)	69.01 (115.64)

Tennis performance and FTF, Tennis performance and the QE. Regression analysis confirmed that the FTF significantly predicted 13% of the variance in tennis Accuracy (Unstandardized β = - .36, t = 2.52, p = .01). Results in turn revealed that FTF also significantly predicted 15% of the variance in the percentage of error made across testing sessions (R^2 = 0.15 β = - .012 p = .001). No such relationship was apparent between QE and error rates or QE and accuracy scores.

2.5.4 Discussion

Experiment 3 was conducted with the aim of combining the objective measurement of eye movements and performance in a cognitive task from Experiment 1, with the interesting application to tennis, as piloted in Experiment 2. Additionally, experiment 3 sought to test the predictions of ACT (Eysenck et al., 2007; Eysenck & Wilson, 2016) with regards to the role of anxiety in disrupting inhibitory control in live sporting tasks. Specifically, a prediction was made that training goal directed inhibitory control processes would protect against the negative influence of anxiety on objective, task-specific measures of attentional control and performance.

The performance data (percentage of missed shots) revealed the predicted interaction effect, with training benefitting participants when performing under heightened levels of anxiety in comparison to their control group counterparts (see Table 1). The training group's performance significantly improved under pressure compared to low pressure, whereas the control group's performance did not change. As the pressure session always followed immediately after the low pressure session, task improvement between conditions could be expected for this novel tennis task if no manipulation was performed in the second condition. Therefore, the training group participants were able to realize these potential task learning effects, whereas the control group's learning was attenuated due to the negative impact of the pressure manipulation.

Another prediction was made that this relative difference in performance under pressure would be driven by attentional differences (cf. Experiments 1 and 2). Indeed, the significant interaction effect for FTF revealed that while the control group demonstrated a diminished ability to inhibit a fixation to the target during ball contact under pressure (revealing a significantly quicker FTF), the training group maintained similar FTFs. Taken together with the performance data, it is apparent that while the training group were insulated from any negative influence of increased anxiety, the control group were not. The regression analysis further revealed that this ability to inhibit a target fixation around the time of contact with the ball was a significant predictor of performance, underlining the importance of optimal top down control for successful sporting execution under pressure (Englert & Oudejans, 2014; Kasper et al., 2012; Vine et al., 2013).

Nonetheless contrary to initial predictions, the relative tracking QE measure did not reveal any significant interaction effects or group differences. Neither did QE duration significantly predict performance. There has been limited research exploring the impact of anxiety on tracking QE in interceptive tasks, compared to the work undertaken on aiming tasks. While Vine et al. (2013) research in golf putting guided the development of our FFT measure, only Causer et al. (2011), in shotgun shooting, have explored the impact of anxiety on tracking QE duration. Perhaps, as in golf putting, anxiety has more influence on the later phases of skill execution, requiring online control, rather than earlier phases involving pre-programming. Subsequent research is needed to further examine the impact of anxiety on attentional control in general, and inhibitory control in particular, in the planning and execution of skilled motor tasks. Alternatively, while an enhanced ability to inhibit potential internal and external distractors may indeed promote longer QE durations, other functions of the central executive of working memory such as switching or updating may also play an important role in lengthening the

QE under pressure and future training studies in sport could employ a more generalized method of training known to directly target the principal function of WM such as inhibition, switching and updating.

To conclude, the positive training effects observed in Experiment 3 are consistent with both previous research employing similar training methods to provide beneficial outcome in healthy and vulnerable populations (Jaeggi et al., 2011, Owens et al., 2013; Sari et al., 2015) and those adopting QE training methods in sport (e.g. Vine et al., 2011; Wood & Wilson, 2011). Two potential advantages of translating attentional training from mainstream psychology, compared to QE training, are that training does not require detailed knowledge of the task specific expert gaze strategy being modelled (i.e. training is more generalized), and, the mechanisms underpinning the improvements in performance under pressure (i.e. improved inhibitory control) are more explicitly targeted.

2.6 General Discussion

The current set of experiments provides encouraging evidence that enhancing the efficiency of the inhibition function (and resistance to distraction) can facilitate sport performance, with considerable benefits in competitive, high-pressured environments. In Experiment 1, results demonstrated that training the inhibition function improved inhibitory control on an untrained anti-saccade task (near transfer). In Experiment 2, results indicated that training-related gains led to improved attentional control during the performance of a tennis service return task (far transfer). Lastly, the outcome of Experiment 3 underlined far transfer effects of training on tennis volleying performance and attentional control when anxiety levels were elevated. Taken together, inhibition training revealed positive effects irrespective of the nature of the task demands (e.g. response format) or the distracting stimuli that needed to be inhibited.

The present results confirm and extend the main predictions of ACTS (see Eysenck & Wilson, 2016, for a review); that it is possible to enhance sporting performance via manipulating and targeting the inhibition function of working memory. They also provide direct evidence that processing efficiency in distractor inhibition can act as a causal mechanism by which attentional control related benefits transfer to sporting performance outcomes. The present results demonstrate that training inhibitory processes of working memory can play a vital role in increasing attentional control related indices of performance, with direct transfer effects on an eye-tracking index of inhibition necessary for accurate performance.

There are a number of ways in which future research can build on the exciting potential of these novel findings. First, future research will need to determine whether the training task provides a generic improvement in inhibitory control, or whether the search object – the tennis ball in the current study - needs to be domain specific. We suggest that the results observed in Experiment 1 were training on the visual search task led improved performance on the Antisaccade task; where neither the participants nor the transfer task were related to tennis; are strongly supportive of a generalizable benefit. Second, the transferability of training effects to other sporting skills should also be examined. For example, would the tennis players in Experiment 3 also reveal better attentional control in other tennis or non-tennis sporting tasks (e.g. tennis serving, or service return)? Third, while the present set of experiments specifically focused on the effectiveness of inhibition training – based on the strong evidence relating distractibility to impaired performance under competitive pressure (Englert & Oudejans, 2015; Oudejans et al., 2011), future research should investigate the efficacy of targeting other executive functions of WM, such as switching and updating, for sport performance (Furley et al., 2015). Finally, whilst the online presentation of the training is a novel and time effective way of delivering cognitive training, future research should ensure that specific procedures are in place to ensure that all participants recruited to undertake training can be identified as the ones doing the daily task. It is worthy to note that since the present data show significant transfer effects across all three experiments, this is unlikely to have been a concern in the present study.

In conclusion, this is the first study to show that training the efficiency of the inhibition function (resistance to distraction) can result in transferrable training-related gains in motor performance in attentionally demanding sports such as tennis. The present results can hopefully pave the way for future research to extend the applications of training to improving attentional control in motor performance to a number of sporting activities under competitive and ego challenging situations. Finally, whilst the results of Chapter 2 strongly suggest that training inhibitory control using a lab based training paradigm can help protect tennis players against the negative impact of competitive pressure by enhancing inhibitory control and gaze behaviours directly related to the ability to resist distraction in tennis.

However the present results did not confirm any benefits of training on the actual QE (i.e. a valid index of attentional control in the field). Whilst it is entirely possible that an increased ability to inhibit distractors could indeed promote longer QE durations, other functions of the central executive of working memory such as switching or updating may also play a crucial part in lengthening the QE. Chapter 3 will therefore attempt to test the potential efficacy of working memory training on tennis performance and the QE employing the dual n-back task which is thought to promote the efficiency on the principal executive functions of WM (i.e. inhibition, switching and updating).

Chapter 3

Testing the Efficacy of Working Memory Training in Improving Cognitive and Motor Task Performance

3.1 Chapter Overview

The set of experiments presented in Chapter 2 employed a lab based training paradigm which was specifically designed to target the inhibition function of the central executive of working memory. The principal aim of Chapter 2 was to explore whether such training method would protect recreational tennis players from the negative impact of competitive anxiety via improved inhibition. Whilst results demonstrated that training inhibitory control in the lab may be sufficient to protect sports performance against the negative impact of competitive pressure by enhancing inhibitory control and gaze behaviours directly related to the ability to resist distraction in tennis, findings from this study did not confirm any benefits of training on the actual QE (i.e. a valid index of attentional control in the field). Whilst it is entirely possible that an enhanced ability to inhibit potential internal and external distractors could promote longer QE durations, other functions of the central executive of working memory such as switching or updating may also play a crucial part in lengthening the QE. The principal aim of Chapter 3 was to test the potential efficacy of the dual n-back training task, a working memory training task though to promote the efficiency on the principal executive functions of WM (i.e. inhibition, switching and updating). Transfer effects of training were initially explored on a change detection task (Vogel et al., 2005), a widely used of index of working memory capacity (WMC). Another critical aim of Chapter 3 was to assess whether working memory training would in turn protect tennis performance from the negative effect of competitive pressure through potential benefits on objective indices of attentional control in the field (i.e. the QE). Lastly, in order to explore the potential generalisability of training to other sporting tasks transfer effects were also assessed on a self-paced dart aiming task in which participants were mostly inexperienced.

3.2 *Experiment 4:Testing the Efficacy of Working Memory Training in Improving Cognitive and Motor Task Performance*

3.2.1 Introduction

Successful performance in sports is commonly evaluated in terms of technical, physical or tactical abilities. However, the cognitive aspects of sports performance also need to be taken into consideration. This is especially relevant when athletes are required to perform complex and fine motor skills under elevated levels of pressure (Nicholls, Holt, Polman, & James, 2005). Indeed, it is not uncommon to witness both amateur and professional athletes' performance breaking down under the perceived pressure of competitive situations (Geukes, Harvey, Trezise, & Mesagno, 2017; Moore, Wilson, Vine, Coussens, & Freeman, 2013).

It was recently suggested that such performance breakdowns can be explained in terms of a reduced ability to sustain optimal levels of attention control (Vine, Lee, Moore, & Wilson, 2013; Eysenck & Wilson, 2016). In sports, attention control is believed to play a crucial role in reducing distractibility and ensuring the efficient preparation and execution of complex motor movements (Wilson, 2012). Such idea is directly derived from recent research in the area of cognitive neuroscience investigating the debilitating effect of anxiety on attentional control and WMC when undertaking specific cognitive tasks (see Berggren & Derakshan, 2013 for a review). According to Engle (2002) WMC reflects an ability to maintain task goals, whilst diminishing potential interference or distractions. Additionally recent models of working memory (e.g. Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000; Unsworth, Redick, Spillers, & Brewer, 2012; Shipstead, Lindsey, Marshall & Engle, 2014) in turn likens attentional control to the relative efficiency of the executive functions of working memory such as inhibition (e.g. resistance to distraction), shifting (e.g. within-task control), and updating in attaining a task goal.

Anxious apprehension as well as worrying about performance have been found to disrupt task execution by reducing working memory capacity and increasing bottom up processing (for a review see Berggren & Derakshan, 2013), supporting one of the main predictions of Attentional Control Theory of Anxiety (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan & Eysenck, 2009). There is now substantial evidence that anxiety related distractibility reduces processing efficiency of working memory, impairing goal directed behaviour (see Moran, 2016; Eysenck & Wilson, 2016, for reviews).

The Quiet Eye (QE) originally introduced by Vickers (1996), is a widely used index of attentional control in sports, defined as the final fixation or tracking gaze towards a relevant target within 3 degree of visual angle or less, occurring prior to the execution of the critical phase of a goal-directed movement. The QE is postulated to support task performance by promoting efficient top down motor preparation and online control functions, and has been shown to be a valid index of task proficiency and expertise across a range of targeting and interceptive tasks (see Lebeau, Liui, Saenz-Moncaleano, Sanduvete-Chaves, Chacon-Moscoso, Becker, et al., 2016, for a recent meta-analysis). In line with the predictions of ACT (Eysenck et al., 2007), the QE is also sensitive to the impact of competitive pressure in both self-paced (e.g. golf putting, Vine, Lee, Moore, & Wilson, 2013; basketball free-throw shooting, Wilson, Vine, & Wood, 2009), and interceptive (e.g. shotgun shooting, Causer, Holmes, Smith, & Williams, 2011) sporting tasks. In these studies, a reduction in QE is also generally associated with a reduction in performance under pressure.

As highlighted in Chapter 2, training interventions have been designed to maintain or increase the QE to protect against performance breakdowns under pressure in skilled performers (e.g. in golf putting, Vine & Wilson, 2011; basketball free throw shooting, Wilson, Vine, & Wood, 2009; shotgun shooting, Causer, Holmes, & Williams, 2011; and football penalty taking, Wood & Wilson, 2011). However, such interventions tend to be task specific and based on the observation of an expert model, with the specific mechanisms by which they exert their effects remaining unknown (Vine Moore & Wilson, 2014). As such, it is not possible to target the specific cognitive mechanisms by which training may protect athletes against the negative impact of anxiety, making it difficult to draw firm conclusions on the role of executive functions and processing efficiency in sports or identify whether anxiety related decrease in performance are directly related to impairments in attentional control.

In an attempt to account for some of the limitations of QE training methods and identify potential cognitive mechanism involved in affecting motor performance under pressure, the set of experiments presented in Chapter 2, employed a training paradigm specifically designed to target the inhibition function of working memory. The aim was to protect recreational tennis players from the negative impact of competitive anxiety via improved inhibition. Compared to a control group, adaptive training improved inhibitory control which led to enhanced tennis specific attentional control in a return of serve task, as well as improved tennis performance and visual attention control on a tennis volleying task. Specifically, relative to their control counterparts, trained tennis players showed a reduction in the percentage of volleys that missed a target in a pressure condition. They also revealed greater task-specific (e.g. tennis specific) inhibitory control; maintaining longer gaze fixations around the area of contact with the ball and resisting the tendency to direct their gaze towards the target to check the outcome of their shots.

A key feature of the findings reported in Chapter 2 was that the training task was designed specifically for improving the functioning of a specific executive function of working memory, namely inhibitory control. Whilst results successfully demonstrated that training inhibition may be sufficient to protect sports performance against the negative impact of competitive pressure by enhancing inhibitory control and gaze behaviours directly related to the ability to resist distraction in tennis, findings from this set of studies did not confirm any benefits of training on actual QE durations (i.e. a valid index of attentional control in sports). This may limit the generalisability of the findings to other sporting disciplines. Whilst it is entirely possible that an enhanced ability to inhibit potential internal and external distractors could alone promote longer QE durations, other functions of the central executive of working memory such as switching or updating may also play a crucial part in lengthening the QE.

More specifically, it is highly likely that the mechanisms involved in the QE rely on the combined processes of these fundamental executive functions, whose interplay determines performance efficiency in sports (Eysenck & Wilson, 2016; Wood & Furley, 2015). For example, the ability to maintain a steady gaze for long periods of time should not only necessitate good resistance to distraction (i.e. inhibition) but also efficient within-task attentional control (i.e. the shifting function). This is consistent with the original predictions of ACT (Eysenck et al., 2007, Derakshan & Eysenck 2009), which denotes that when confronted with elevated levels of pressure, fundamental executive functions of working memory are affected by anxiety, reducing processing efficiency of WM. Moreover, there is compelling evidence for an anxiety-related impairment on major executive functions of working memory involved in sports. Indeed, whilst Chapter 2 largely emphasized the involvement of inhibition in promoting efficient performance in competitive pressurized settings, the involvement of the switching function as well as general WMC on sports performance has been previously discussed in the sports literature (e.g. Castiello & Umilta, 1992; Han et al., 2011; Wood et al, 2016)

More specifically, in a recent study exploring the negative impact of anxiety on the QE in a shooting task, Wood, Vine and Wilson (2016) found that when compared to individuals with high WMC, those with low WMC generally displayed impaired visual search time to locate a target as well as poorer aiming behaviour suggestive of greater attentional disruptions under pressurized conditions. In terms of the switching function Castiello and Umiltà (1992) observed that professional volleyball players tended to shift attention to cued visual targets faster than control participants. In another study Han et al. (2002) showed that higher ranking baseball players displayed fewer preservative errors that lower ranking players on the Wisconsin card sorting task indicating that the more proficient players displayed a superior ability to shift their attention.

Another plausible explanation for the lack of transfer effects found on the QE in Experiment 3 of Chapter 2 is that transfer-related gains from training one specific function to other functions and sports performance outcomes whose success relies on the inter-play of a number of fundamental processes of working memory including functions of updating, switching as well as inhibition, can be difficult and not always attainable (Koster, Hoorelbeke, Onraedt, Owens, & Derakshan, 2017). Specifically, recent evidence points towards the fact that neuro-plasticity induced change from training more fundamental working memory processes versus the training of single functions such as inhibition is likely to result in far transfer effects to untrained tasks (Koster et al., 2017).

Capitalising on the encouraging findings presented in Chapter 2 and promising recent findings that adaptive working memory training targeting fundamental executive functions of WM can enhance attentional control and performance outcomes in anxiety (Sari, Koster, Pourtois & Derakshan, 2016), worry (Course-Choi, Saville & Derakshan, 2017) and depression (Owens Koster & Derakshan, 2013), the current experiment was designed to assess the effects of adaptive working memory training on tennis volley performance under pressure.

The present experiment employed the adaptive dual n-back training task which has been shown to increase fluid intelligence (Buschkuehl, Jonides, & Perrig, 2008; see Au, Sheehan, Tsai, Duncan, Buschkuehl & Jaeggi, 2015 for a review) and is argued to have transfer related benefits on working memory capacity, boosting processing efficiency and reducing emotional vulnerability-related impairments on performance (Sari, Koster, Pourtois & Derakshan, 2016; Course-Choi et al. 2017; Owens et al, 2013; see also Koster et al., 2017 for a review). A translational implication of these findings is that adaptive working memory training through its effects on executive control functions of working memory could boost performance efficiency in pressurised sports settings as measured by the QE. A prediction was made that a sample of experienced tennis players allocated to a training group relative to their control counterparts would show more efficient attentional control (display longer QE durations) and superior tennis volleying performance under pressure, when working memory demands will be at their greatest.

Last but not least, based on initial research by Vickers and Rodrigues (2002), Nibbeling et al. (2012) and Englert et al. (2015) who showed that longer QE were associated with better accuracy in darts, Riehnoff, Hopwood, Fischer, Strauss, Baker and Schorer (2013) demonstrated that participants who undertook basketball specific QE training also tended to display enhanced performance in a non-trained dart throwing task. The tennis volleying task employed in this study is an interceptive task where both resistances to distraction and efficient object tracking appear to be essential in maintaining optimal performance. However, a secondary aim of the study was to test whether WM training would benefit performance on a self-paced dart task through enhanced attentional control (i.e. the

QE in darts) to show more generalised transfer of WM training to another sporting task in which participants were not proficient. Specifically, it was hypothesized that potential training related gains would also transfer to performance on a dart task performed under pressure as well as on the QE in darts.

3.2.2 Methods

Participants

Participants were recruited from an opportunity sample of recreational club tennis players who engage in competitive tennis activities between 1 and 3 times per week at a London based Tennis Club. The sample included 30 participants (21 males, 9 females; *M* age = 33 years, range: 17 to 50). A power analysis was conducted prior to recruiting participants (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007) to determine an acceptable sample size. This analysis indicated that based on an effect size of ηp^2 = .30 on the FTF gaze index observed in Experiment 3 of Chapter 2 study, 24 participants were considered sufficient to achieve a power of 0.8 in an *F* test, given α = .05. Nevertheless 30 participants were recruited to account for potential dropout during the training period and potential loss of gaze data which can occur following calibrations issues when employing portable eye tracking equipment. Participants were initially matched on pre-test measures of trait anxiety (Control *M* = 41.15, *SD* = 7.48; Training *M* = 43.00, *SD* = 7.6), age (Control *M* = 2.58, *SD* = .77; Training *M* = 2.62, *SD* = 1.09) and tennis accuracy performance (Control *M* = 32.46, *SD* =13.60; Training *M* = 34.76, *SD* = 13.29) and pseudo-randomly allocated to an active control or a training group. All participants gave informed consent and were debriefed at the end of the experiment. Ethical permission was obtained prior to the study.

Materials and Stimuli

Adaptive Dual n- back Training Task (see Figure 3.1). The training task was derived from the task employed in Owens et al. (2013) which was itself based on the original work of Jaeggi, Buschkuehl, Jonides, and Perrig (2008). All trials started with a green central fixation cross which appeared in the centre of the screen. Participants were then presented with a 3x3 grid within which a green square appeared at one of 8 possible locations. During the presentation of the green square, one of 8 possible consonants (c, h, k, l, q, r, s, t and t) was also verbally presented. Participants were required to memorise the position of the square as well as the letter spoken and asked to respond whenever either of the audio or visual stimuli previously presented matched the letter spoken or the position of the green square (n) trials back. Both sets of stimuli were presented at a rate of 500ms and each trial was separated by a 2,500ms interval. Participants made their response by pressing “L” for auditory matches and “A” for visual matches. Participants were also informed not to respond to non-matches and to simultaneously press “L” and “A” if both auditory and visual stimuli did match. They were also asked to make their response as quickly and as accurately as possible. Each training session comprised of 20 blocks with 20 + n trial in each (for example, in a 2-back block there were 20+2=22 trials; in a 3 back block there were 20+3=23 trials). Each blocks contained an equal number of matches (4 for the position, 4 for the letter, and 2 for both). The location of the square and the letter spoken were randomly distributed within each block. A 15 seconds fixed break was programmed between each block and the task could not be terminated once it was started. Each session lasted around 30 minutes.

Adjustments in the level of task difficulty (n) were contingent on participants' performance on the task. If accuracy on both the position and letter match elements reached 95% or above, the level of n increased by 1 in the following block. If accuracy rates were between 75% - 95%, participants remained on the same level. If their performance declined (less than 75% accuracy), task difficulty also decreased by one level of n. Participants were given written information about level difficulty upon starting each block.

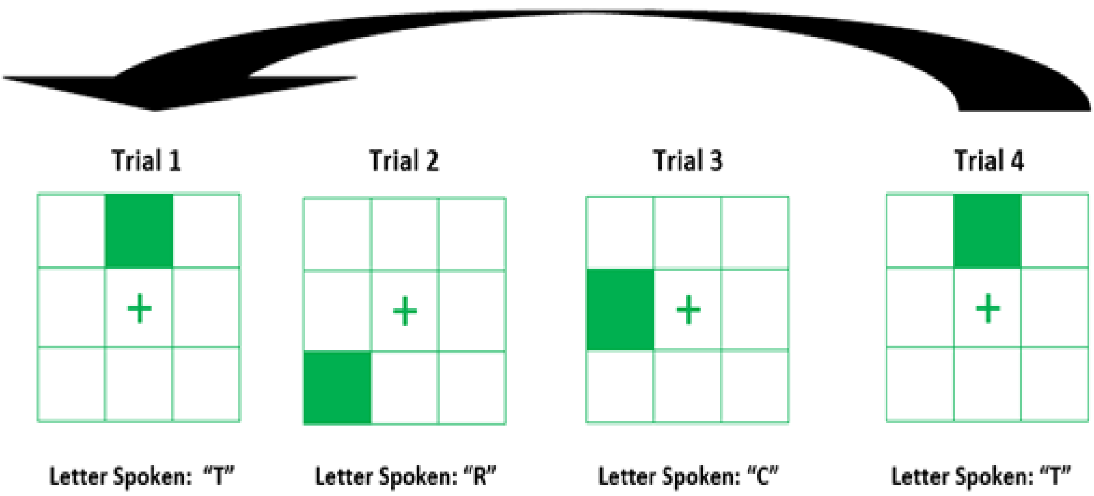


Figure 3.1: *An example of a 3-back level trial on the dual n-back training task.*

Non-adaptive dual 1-back control task. The control group undertook 20 blocks of dual 1-back trials across the ten days of training irrespective of their performance achievement. This task followed the same basic procedure as the adaptive training task with participants being required to respond if they either noticed a position or a letter (or both) match with the preceding trial (1-back). No level increments were in place for the control task.

Both training tasks (adaptive and non-adaptive) were delivered online using PHP and JavaScript (jQuerry; see Procedure). Accuracy rate for each training block for each participant was recorded online and task performance was routinely monitored remotely by the experimenter.

Tennis volley task. A modified version of the volleying task employed in Chapter 2 (Experiment 3) was designed for this study. In contrast to Experiment 3 in chapter 2, where the tennis balls were fed by hand, a ball machine was employed to provide a more consistent delivery. Participants were required to execute a series of volleys as accurately as possible onto a 120cm x 120cm Federation International de Tir a l'Arc (FITA) approved archery target placed on a blank wall at a distance of 500cm from the player and 100cm from the floor. The volley task comprised 20 trials, divided into a block of 10 forehands and a block of 10 backhands. A set of 10 Dunlop Fort All Courts balls and a Babolat Pure Drive tennis racket were employed for the duration of the study. The ball was delivered from a ball machine (Tennis Tutor Tennis Cube), which was placed centrally below the target and against the wall. The speed of the ball feed was kept constant for all participants and throughout all pre and post trials with ball speed being set on the machine at 3 on an existing scale of 1 to 5 (a speed of 22 mph). Time interval between ball deliveries was also kept constant with every ball being delivered at a frequency of one ball every 6 seconds. For both backhand and forehand blocks, the ball machine was positioned at an angle of 16˚. This was determined through pilot testing so players were able to reach the ball with a straight arm to execute their shot. Additionally, the height of ball delivery was also determined in pilot testing with the height of the delivery system of the machine being set at an angle of 25˚. This enabled participant who were standing 500 cm away from the machine to consistently make contact with the ball between waist and shoulder height.

Darts throwing Task. The tennis field task was derived from previous research looking at the QE in darts (Vickers et al., 2000; Riehnoff et al., 2015). The dart target employed for the present study was a regulation 'soft tip' target which was set on a stand. In accordance with official tournament regulations the Bull's Eye was set at a height of 173 cm and participants were required to execute their throws from a distance of 237cm. A set of 5 soft tip darts weighing 22 g was employed for the duration of the study. In all conditions, participants were required to thrown 20 darts in 4 blocks of 5 throws.

Measures

Change detection Task (CDT). The task employed to evaluate participants' working memory capacity (WMC) was a shortened version of the Change Detection Task (CDT) employed in Owens et.al (2013) which was itself based on the task initially utilized by Vogel et al. (2005) (see Figure 3.2 and 3.3). The CDT was programmed using E-prime software and delivered on an HP Pavilion 15inches laptop set at a resolution of 1024 × 768 (refresh rate 65 Hz). The task comprised a total of 192 trials, which were divided into 4 blocks of 48 trials. Each trial consisted of two stimulus arrays, a memory array and a test array. The task began with a fixation cross appearing in the centre of the screen followed by an arrow serving as a cue and pointing either to the right or left of the fixation cross for 700ms. The memory array subsequently appeared for 100ms which was followed by a retention array which lasted 900ms and consisted of 2 sets of up to four blue or red rectangular shapes. The last array was a test array, which appeared for 2000ms.

Each array consisted of either two or four rectangles (0.64° x 1.21°), which were randomly positioned within a 4° x 7.2° rectangular region and spaced around 2° apart. The 2 regions were positioned approximately 3° from a white central fixation cross on a black background. All rectangles were randomly orientated along one of four positions (vertical, horizontal, left 45°, right 45°). The experiment comprised 3 conditions, dependent on the number of red rectangles present (2 or 4). Lastly the distractor condition contained 2 blue rectangles and 2 red rectangles. For all conditions, on 50% of the trials, no change in the orientation of any of the red rectangles occurred from the memory array to the test array. For the other half of the trials the orientation of one of the red rectangles did change between the memory array and the test array. The number of items comprised in the arrays as well as the direction of the arrow and the type of trials (change vs. no change) were randomized across blocks and appeared at the same frequency across the whole experiment.

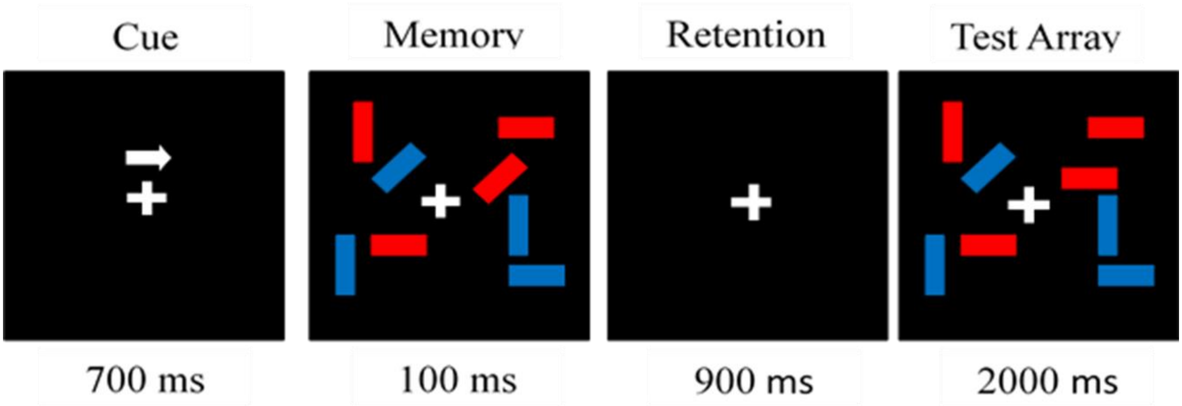


Figure 3.2: *Example of a change trial in a distractor condition. Participants were required to memorize the orientation of the red rectangles in the memory array and instructed to respond if the orientation of one of the red shape had changed in the test array.*

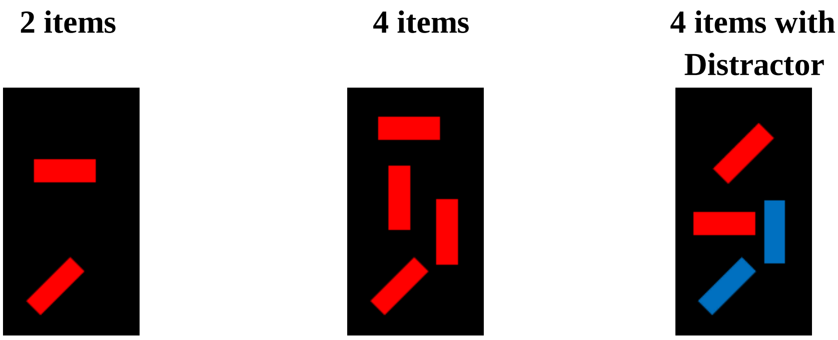


Figure 3.3: *Example of the three different conditions included in the CDT.*

State anxiety. As in Chapter 2 Cognitive anxiety was measured using the Mental Readiness Form (MFR-3; Krane 1994) and was assessed at 3 time points during all pre and post tennis tasks (before the first block of 10 shots, midway through the tennis task and as soon as the task ended), and a mean value was used in subsequent analyses.

Tennis volley performance. Tennis performance was assessed in terms of shot accuracy, obtained by determining where the ball bounced within the scoring rings on the archery target, from post-test analysis of video footage. Accuracy scores for each shot ranged from 0 to 10 with 0 being a miss (ball landing outside the target) and 10 being scored when the ball hit the centre area of the target. For each participant the analysis included the average accuracy scores of all shots executed in each condition. As in Experiment 3 in Chapter 2 the percentage of error on the tennis task (i.e. shots missing the target) was also calculated.

Darts performance. Darts performance was assessed in terms of radial error or more precisely as an evaluation of how far each dart landed from the centre of the target. Radial error for each thrown dart was measured as a distance in millimetre from the centre of the target to the landing location of each dart. This was done on screen using the footage of the external camera and a computer ruler (MB ruler, http://www.markus-bader.de/MB-Ruler/index.php) allowed to measure distances in millimetres. This distances were then converted to real life measures (in cm).

Gaze measures and video data. 'Pupil lab' Eye Tracking head mounted glasses were employed to measure and record momentary gaze. The scene camera captured video data at 30 Hz (resolution, 1024x720p) while the eye cameras captured eye movements at a rate of 60 Hz. The pupil labs eye tracker was set to capture pupil positions with the gaze position 2D fixation detector. A circular cursor (representing 1° of visual angle) indicating the location of gaze in a video image of the scene (spatial accuracy of ± 0.6° visual angle; 0.08° precision) was recorded for offline analysis. Recording of motor movements and analysis of the data employed the procedure highlighted in the method section.

Quiet eye (QE) Tennis task. As in chapter 2 the QE period for the tennis volleying task was operationally defined as the final fixation on the ball prior to the initiation of the forward swing of the racquet (see method section of general introduction).

Phase Durations tennis task. The durations of the phases of the tennis volley were calculated using Quiet Eye Solutions software (Quiet Eye Solutions Inc., Calgary, CA) (see method section of general introduction).

QE Dart task. For the Darts task QE was defined as the final fixation on the Bull's eyes occurring before the forward movement of the throwing forearm (defined from the view of the scene camera of the eye tracking system as the hand was always visible in the footage). Specifically, QE onset occurred prior to the forward movement of the forearm QE offset occurred when the gaze deviated off the bull eyes by 1° or more, for 100ms or more.

As in Vine et al. (2011) ten percent of the video data was independently analysed by a second independent rater, who was blind to both the aim of the experiment and participants' group allocation. Results revealed high levels of agreement between the two raters for the for the QE period in tennis, $r = .93$, $p < .001$ and the QE period in darts, $r = .92$, $p < .001$.

FTF (first target fixation): As in Chapter 2, Experiment 3, the FTF was operationally defined as the length of time in milliseconds that elapsed between racquet to ball contact and the onset of a fixation on the target. Longer durations therefore reflect an optimal strategy similar to that identified by Lafont (2007, 2008) and more efficient inhibition of the target.

Procedure

The design of the experiment followed a pre-intervention, intervention, post-intervention format. Participants were tested individually and arrived at the testing venue (a squash court at the Tennis Centre), to first perform the CDT task; hitting the 1 key when they detected a change and the 0 key if no change was observed. The CDT task started with a training block of 12 trials. Once the practice block was completed with at least 50% accuracy, participants were instructed to undertake the full CDT task, which lasted around 10 minutes. Upon completing the CDT task participants were given brief instructions on how to proceed with the online home training task and undertook a short practice on the tennis task in order to warm up and get familiar with the speed of the ball delivery.

The eye-tracking equipment was then fitted and calibrated using a 6-point calibration procedure. Participants were then asked to complete the MRF-3. Participants were required to volley a tennis ball delivered by a ball machine, onto an archery target attached to a blank wall. Participants were instructed to stand with both feet on a designated line whilst keeping a steady ready position, holding their racquet with both hands at around waist height. Upon finishing the first block of 10 volleys, participants were required to complete the MRF-3, which was completed again at the end of the whole task. Following completion of the tennis task participants undertook 5 practice throws on the dart task whilst still wearing the eye-tracking equipment. Participant then undertook the dart task. For each throw participants were instructed to elevate their elbow at a right angle as a starting position. Participants were required to respond to the MRF-3 upon starting the task, and after the first 10 throws and upon completion of the 20 throws. Since soft tip darts were used for the study any throwing attempts which bounced off the target were retaken.

Following the pre testing sessions, participants were introduced to the online training task, and were later sent a designated web link directing them to the experiment website. They were told that they should complete 10 days of training within a two-week period and to undertake the task at approximately the same time every week-day. Participants were given automatic feedback of their daily performance and progress at the end of each session and told that their performance and completions rates would be monitored on a daily basis. After the two-week period, participants were invited back to the lab again for the post intervention testing session.

In the post-training session, participants first completed the same procedures as in the pre-training session. However, following the initial tennis session and dart sessions participants were required to repeat the tennis task and the dart task in a pressurized condition. As in Experiment 3 Chapter 2, pressure was manipulated and participants were told that their data may be used in a proposed sports science TV program with performance being evaluated by tennis experts against the performance of other participants taking part in the study (a mock consent form which included TV branding was completed). Participants were also told that the tennis experts would analyse their facial expression during the task.

Lastly, they were told that a ranking system based on their tennis accuracy scores was in place. Non-contingent feedback was provided, with participants being informed that their scores from their previous tennis performance would put them in the bottom 30% of the pool of participants. They were in turn told that should their performance remain at this level their data could not be used for the experimenter's PhD study. Upon completion of the pressure condition participants were debriefed about the study's aims and thanked for their participation. Participants were compensated with £45 pounds for around 6 experimental hours of participation.

Data Analysis

One participant in the control group and two participants in the training group dropped out during the testing phase of the study. Another participant was excluded following the pre testing session due to an inability to perform the tennis task, and the data of one participant could not be used in the analysis due to poor calibration of the eye tracking equipment. The analysis was therefore conducted on a final sample of 25 participants (13 Control and 12 Training).

CDT Task. Working memory capacity (CDT task) was calculated employing the widely used formula (Pashler, 1988): K = S x (H - F) / (1-F). Specifically, K (WMC) was calculated as a function of S (the set size of the array), H (the observed hit) rate and F (proportion of false alarms). In line with previous research employing the CDT task (Lee, Cowan, Vogel, Valle-Inclan and Hackley, 2010; Owens et al., 2013), WMC was calculated for the 4-item condition.

***Tennis and Dart performance*.** As there were no group differences between any of our dependent variables at pre-test[1], the analysis solely focused on the post training conditions (Low pressure vs. High pressure). Dependent variables were therefore subjected to 2 x 2 Group (Control vs. Training) x Condition (Low vs. High pressure) mixed analyses of variance. Linear regression analyses were also conducted to assess whether each index of gaze behaviour (QE, and FTF) predicted tennis performance (total accuracy scores and total number of misses aggregated across both Low and High pressure testing sessions).

Training Task Manipulation Check. Figure 3.4 shows performance improvements on the Dual n-back task for the training group. Performance on the training task improved across the period of training with participants attaining greater levels of difficulty towards the end of training (mean of last two days of training M = 2.88, SD = .76), compared to the mean of first two days of training (M = 1.88, SD = .61), $t(12) = 5.34$, $p < .01$. By comparison, the control group showed 94.64 % accuracy overall and their scores did not vary from the first n-back session (93.92 %) to the last n-back session (95.46 %), $t(11) = 1.14$ $p = 0.27$.

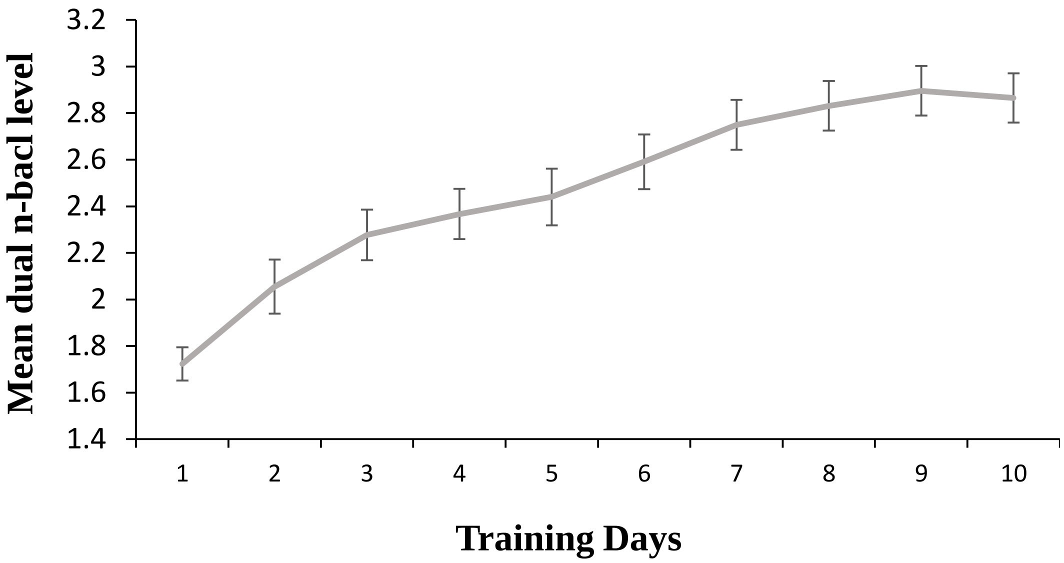


Figure 3.4: *Mean dual n-back level across training days. (Error bars = SEM).*

Footnote

[1] In the pre testing session, the tennis QE durations for both control (*M* = 428.84ms, *SD* = 42.87) and training groups (*M* = 432.30ms, *SD* = 63.74) were similar (t<1). The timing of the QE Offset relative to the release of the ball by the machine was also similar for both training (*M* = 542.50ms, *SD* = 24.89) and control groups (*M* =549.01ms, *SD* = 33.49), as was the timing of the QE onset (training; *M*=115.21ms, *SD* = 49.85 vs control; *M* = 110.38ms, *SD* = 34.65; *t*'s<1). The FTF index was also similar at pre testing for control (*M* = 182.24, *SD* =56.06) and training group (*M* = 168.34, *SD* = 65.75) Lastly in the pre testing session, tennis accuracy scores did not differ between the control group (*M* = 2.58, *SD* =.77) and the training group (*M* =2.68, *SD* =1.11), $t < 1$. For the Darts task QE results were similar in pre testing session for both control *(M* = .819, *SD* = .34 and training group (*M* =.842, *SD* = .63) $t < 1$. In addition Accuracy scores on the dart task did not significantly differ between control (*M* = 10.98, *SD* = 1.92) and training group (*M* = 9.6, SD = 1.78), $t(24) = 1.87$, $p = 0.08$.

3.2.3 Results

Training Task Manipulation Check. Figure 3.4 indicates that participants allocated to the training group performed at higher levels of difficulty on the adaptive dual n-back as training progressed. The mean value of ‘n’ for the last two days of training ($M = 2.88$, $SD = .76$) was significantly higher than the mean for first two days of training ($M = 1.88$, $SD = .61$), $t(12)$ 5.34, $p < .001$. On the other hand participants allocated to the control group maintained similar high levels of accuracy on the 1-back test throughout training. The mean accuracy score in the first two days of training ($M = 95.52$ %, $SD = 2.27$) was not significantly different ($t(11) = 1.03$, $p = .300$) to the mean of last two days of training ($M = 96.47$ %, $SD = 3.15$).

CDT task (WMC). Figure 3.5 shows K (Working Memory Capacity; WMC) scores on the CDT task for both training and control groups. ANOVA revealed no significant main effect of time, or group ($F < 1$). However, there was a Time X Group interaction, $F(1, 23) = 8.56$, $p = .008$, $\eta^2p = .27$. This interaction was driven by a significant increase in WMC for the training group $t(11) = 2.62$, $p = .02$ (Pre $M = 1.14$, $SD = .11$; Post $M = 2.09$, $SD = .88$), compared to the control group who revealed no significant improvement in K scores between the two testing sessions, (Pre $M = 1.68$, $SD = .87$; Post $M = 1.32$, $SD = 1.16$), $t(12) = 1.61$, $p = .131$.

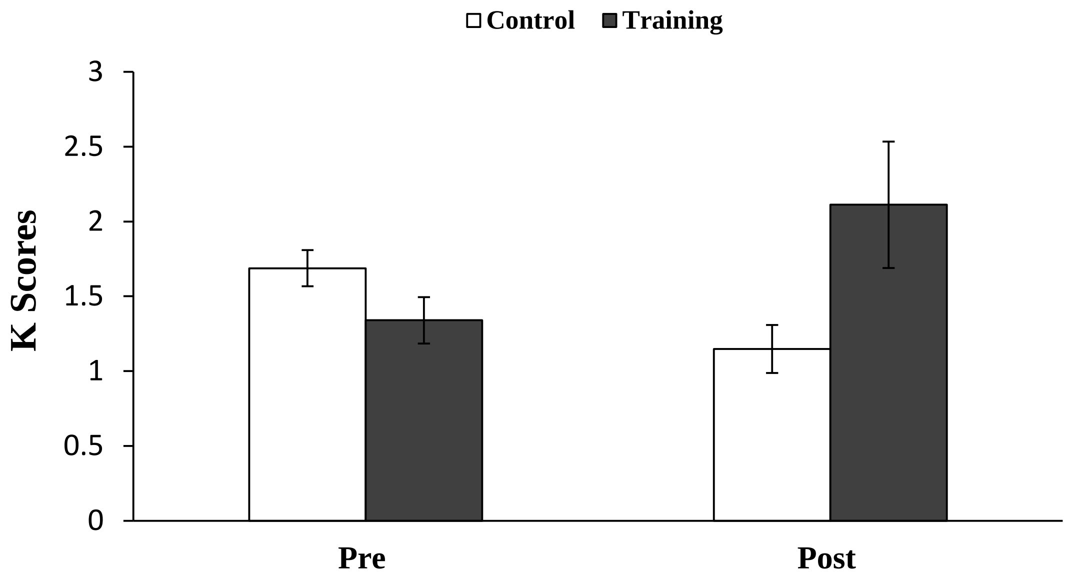


Figure 3.5: *Mean K scores on the change detection task (Error bars = SEM).*

Cognitive Anxiety*:* ANOVA revealed a significant main effect of Condition, $F(2, 44) = 16.16$, $p < .001$, $\eta^2p = .40$ with participants reporting significantly higher levels of cognitive anxiety in the high pressure ($M = 4.25$, $SD = 2.01$) compared to the low-pressure condition ($M = 3.41$, $SD = 1.24$) indicating that the pressure manipulation was successful. There was no main effect of Group, nor a Condition x Group interaction, $Fs < 1$, reflecting that both groups had similar emotional responses to the pressure manipulation.

Tennis Performance

Tennis accuracy. ANOVA revealed no main effects for Group ($F < 1$), but a significant main effect of Condition, $F(1, 23) = 7.58$, $p = .01$, $\eta^2p = .248$. There was also a Condition X Group interaction, $F(1, 23) = 4.535$, $p = .044$, $\eta^2p = .165$. This interaction was driven by a significant increase in accuracy scores for the training group, $t(11) = 3.208$, $p = .008$ (Low pressure $M = 2.67$, $SD = 1.15$; High pressure M = 3.44, SD = 1.62), compared to the control group who revealed no significant improvement between the two testing conditions, (Low pressure M = 2.56, SD = .79; High pressure M = 2.65, SD = .99), $t < 1$. Volley accuracy scores are presented in figure 3.6 and Table 3.1.

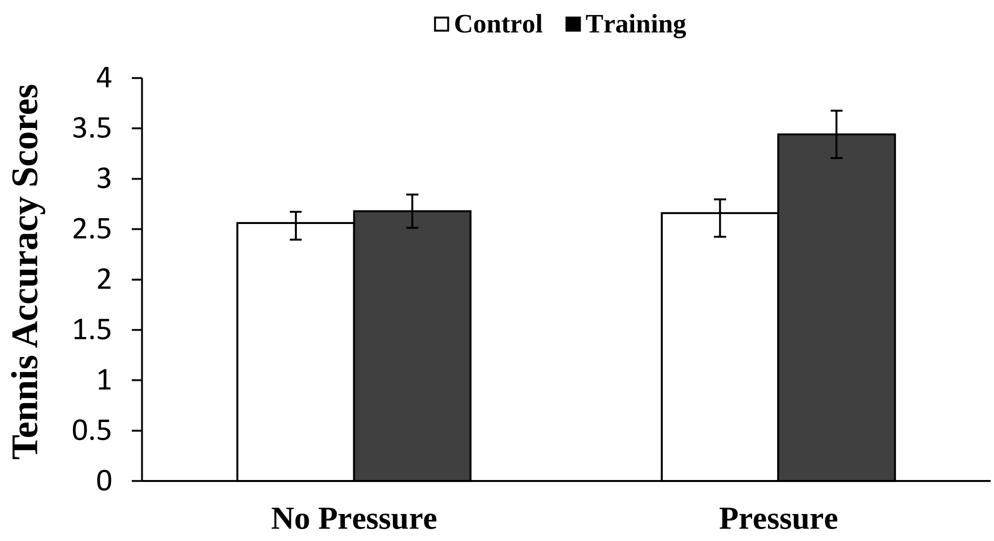


Figure 3.6: *Mean Tennis accuracy scores (0-10) for both training groups across post-training non-pressure and pressure testing conditions (Error bars = SEM).*

***Tennis Errors*:** Table 3.1 shows the percentage of shot missed on the tennis volleying task. ANOVA revealed a significant main effect of Condition, F (1, 23) = 13.29, $p < .01$, $\eta^2p = .336$ with participants generally showing a reduction in the percentage shot missed from Low pressure (M = 43.20 %, SD = 18.97) to High pressure (M = 33.80 %, SD = 21.90) condition. However, there was no Condition X Group interaction, $F < 1$ and the main effect of Group was not significant $F < 1$.

QE Period (QE). 6.21 % of trials across testing sessions were lost due to gaze not being registered. ANOVA revealed a significant main effect of Condition, *F*(1, 23) = 4.61, *p* = .04, η^2p = .16 indicating that QE durations were generally longer in the High pressure (*M* = 446.58 ms, *SD* = 45.26) than in the Low pressure condition (*M* = 432.63 ms, *SD*= 45.75). There was no significant Condition X Group Interaction *F*(1, 23) = 1.90, *p* = .18, η^2p = .07, nor a main effect of Group (*F* < 1; see Table 3.1).

QE Onset (QE-ON). ANOVA revealed neither a significant main effect of condition *F*(1, 23) = 2.08, *p* = .16, η^2p = .083, nor a main effect of group, nor a significant Condition X Group interaction (*F*s < 1; see Table 3.1).

QE Offset (QE-OFF). ANOVA revealed a significant main effect of Condition, *F*(1, 23) = 4.96, *p* = .03, η^2p = .17 indicating that QE Offset generally occurred later in the `High pressure (*M* = 554.13 ms, *SD* = 27.98) than in the Low pressure condition(*M* = 547.88 ms, *SD* = 27.98). There was also a Condition X Group interaction, *F*(1, 23) = 9.05, *p* = .006, η^2p = .28. This interaction was driven by a later occurrence of the QE offset for the training group in the High pressure (*M* = 561.13 ms, *SD* = 24.26) than in the Low pressure condition (*M* = 545.59 ms, *SD* = 21.57), *t(*11) = 3.74, *p* = .003; compared to the control group who revealed no significant differences between the two conditions, (Low pressure *M* = 550.00, *SD* = 29.84; High pressure *M* = 547.66, *SD* = 30.43), *t* < 1. The main effect of Group was not significant *F* < 1. QE offset data are presented in Figure 3.7.

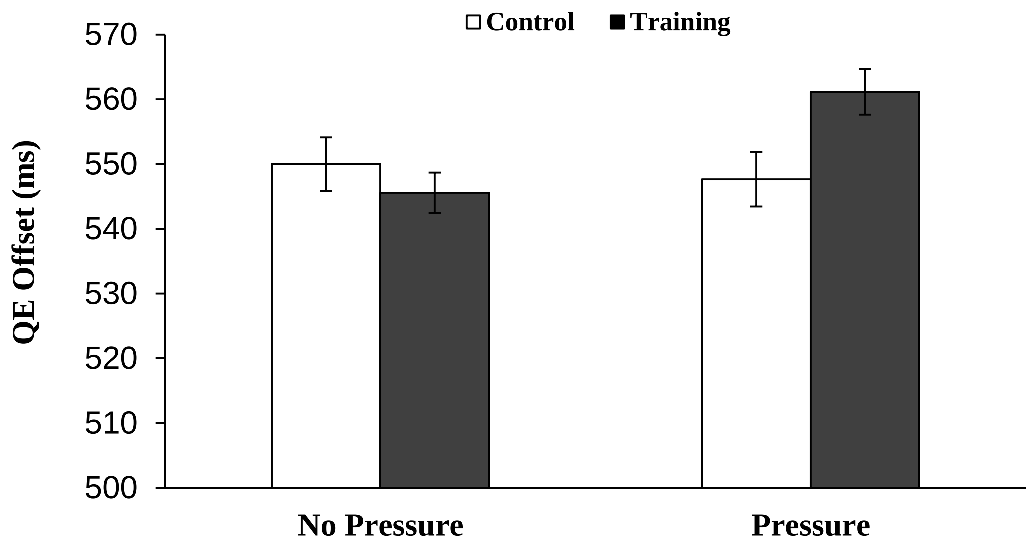


***Figure 3.7**: Mean QE offset (ms) for both training groups across post-training non-pressure and pressure testing conditions (Error bars = SEM).*

First Target Fixation (FTF). 8.01% of trials across testing sessions were lost due to gaze not being registered or participants not making a direct fixation at the target following contact with the ball. ANOVA did not reveal a significant main effect of Condition, Group nor a significant Condition X Group interaction (all *Fs* < 1) (see table 3.1).

Regression analyses conducted on the scores obtained in the two post training session (i.e. Low pressure and High pressure) revealed that the QE significantly predicted 26% of the variance in tennis accuracy scores (R^2 = .26, β = - .014, t = 4.20, p < .01) and that QE in turn predicted 31 % of the variance the percentage of shots not reaching the target (i.e. error rates) (R^2 = .31, β = - .051, t = - 4.70, p < .01) with shorter QE being related to more errors made on the tennis task. Subsequent analyses did not reveal any significant relationship between FTF and tennis accuracy scores nor between FTF and error rates on the tennis task.

Table 3.1: *Mean tennis performance and gaze behaviours scores with standard deviations.*

		Tennis Performance	Gaze Performance		
Condition	Group	Errors %	QE Period (ms)	QE On (ms)	FTF
Low Press	Training	42.91(24.44)	435.40 (47.06)	110.13 (34.28)	157.39 (73.45)
High Press	Training	30.83 (24.19)	459.09 (49.08)	102.06 (36.00)	159.80 (73.59)
Low Press	Control	43.46 (13.13)	429.89 (46.26)	120.13 (34.28)	143.71 (50.45)
High Press	Control	36.53 (20.14)	435.04 (39.87)	111.15 (28.54)	143.02 (84.99)

Darts Accuracy. Table 3.2 shows dart accuracy and darts QE durations. ANOVA did not reveal a significant main effect of Condition, Group nor a significant Condition X Group interaction (all *Fs* < 1).

Darts QE Period. 6.79 % of trials across testing sessions were lost due to gaze not being registered. ANOVA revealed no significant main effect of Condition, $F(1, 23) = 3.258$, $p = .08$, $\eta^2p = 124$. However, results revealed a Condition X Group interaction, $F(1, 23) = 6.81$, $p = .01$, $\eta^2p = .22$. This interaction was driven by a longer QE period for the training group $t(11) = 2.53$, $p = .02$ (Low pressure $M = 780.6$ ms, $SD = 29.12$; High pressure $M = 939.2$ ms, $SD = 40.30$), compared to the control group who revealed no significant differences between the two testing sessions, (Low pressure $M = 678.9$ ms, $SD = 28.02$; High pressure $M =$

649.9 ms, *SD* = 36.4), $t < 1$. The main effect of Group was not significant $F(1, 23) = 2.24$ $p = 0.1$ $\eta^2 p = .08$

A Regression analysis was conducted on dart accuracy scores obtained in the two post training session (i.e. pressure and non-pressure) revealed that the QE period did not significantly predict darts performance ($R^2 = .04$, $\beta = -.61$, $t = 1.43$, $p = .15$).

***Table 3.2**: Mean dart performance and gaze behaviours scores with standard deviations (in parentheses)*

		Dart Performance	
Condition	Group	Accuracy (cm)	Dart QE (ms)
Low Pressure	Training	8.94 (1.81)	780.6 (29.12)
High Pressure	Training	8.75 (2.10)	932.2 (40.3)
Low Pressure	Control	10.84 (1.26)	678.9 (28.02)
High Pressure	Control	10.97 (1.60)	649.9 (36.14)

3.2.4 Discussion

3.2.4.1 Discussion of Main Findings: Working Memory and Tennis Tasks

The current experiment was conducted to investigate whether employing a lab based adaptive cognitive training method specifically designed to target the efficiency of the principal executive control functions of WM, could improve field performance in tennis players when confronted with elevated levels of competitive pressure. It was predicted that enhancing WM capacity as a result of training on the adaptive dual n-back training task, would result in transferrable benefits on WMC and processing efficiency which in turn would protect tennis players against the negative impact of competition related anxiety on objective indices of attentional control and performance outcomes in a tennis volleying task performed under pressure.

Results initially revealed a near transfer effect of training. More precisely, it was found that working memory training resulted in transferrable gains to working memory capacity as measured by the CDT task, a widely used index of working memory capacity. Specifically, participants allocated to the training group displayed a significant increase in working memory capacity scores following training, a benefit that was not evident in the active control group. The training related gains observed in working memory capacity are in line with previous research employing the dual n-back adaptive training paradigm in both healthy and vulnerable populations (Jaeggi et al., 2008; Jaeggi et al., 2011, Owens, et al., 2013, Siegle et al., 2014; Sari et al., 2015; Course-Choi et al. 2017). These findings therefore importantly suggest that targeting executive control functions of working memory using adaptive cognitive training tasks that systematically engage and exercise fundamental executive functions of working memory, can enhance processing efficiency and improve performance outcomes that depend upon the efficiency of these functions.

Importantly, the present results also indicate that it is possible to find far transfer effects of adaptive WM training on sporting performance under heightened levels of pressure - when WM demands are high. Results revealed an improvement in participants' tennis accuracy performance under heightened levels of pressure in comparison to those allocated to the control group. The training group's tennis performance significantly improved under pressure relative to the non-pressure post training session, whereas tennis performance for the control group remained at similar levels. Pressure did not cause a decrease in performance (cf. choking) for the control group, but instead it appears as though increased pressure diminished potential learning effects that would be expected due to the high pressure condition always following the low pressure condition. As such, these results extend previous findings reported in Chapter 2 and suggest that adaptive cognitive training can protect tennis players from the negative effect of competitive anxiety.

The QE duration results mirrored the tennis performance results in terms of this significant main effect for condition (both tennis performance and QE durations being greater under high, compared to low pressure). Additionally, QE duration was found to predict tennis accuracy. While this supports a functional role for QE in underpinning accurate performance (see Lebeau et al., 2016 meta-analysis), there was no additional interaction effect for QE duration. The lack of variance in QE onset across conditions or groups (tennis balls were delivered using a ball machine, which reduced any potential advantage of picking up early information from an early QE onset) may partly explain why the overall QE duration was not sensitive enough to reveal why WM training revealed the far transfer effect. Instead, the training effect observed on tennis performance appears to have been modulated by extensions in the later phase of the QE period. Specifically, participants in the training group did reveal significantly later QE offset under pressure than those allocated to the control group. Previous research has revealed that the QE offset may be particularly sensitive to the influence of pressure – in golf putting (Vine et al., 2013), basketball shooting (Oudejans Langenberg & Hutter, 2002) and dart throwing (Nibbeling, Oudejans & Daanen, 2012) – and the present results support this contention in an interception task.

The importance of maintaining a later QE is related to the suggestion that overt gaze shifts from an object to be struck (e.g. a ball) are preceded by a covert attentional shift occurring earlier (Vickers, 2007). Maintaining a later QE offset therefore provides conditions by which both overt and covert attention are more likely to be maintained on the contact area at the moment of impact. While previous research has revealed that this attentional strategy can be explicitly taught (Vine et al., 2011; Moore et al., 2012), the current study reveals that similar benefits can be achieved by targeting general functions of WM involved in the efficient execution of such actions.

As it was mentioned above gaze data indicated that QE Duration significantly predicted tennis accuracy performance and the percentage of shots that were missed. This was not the case for the FTF (i.e. index of resistance to distraction in tennis) as it was shown in Experiment 3 of Chapter 2. The fact that the QE predicted performance rather than the FTF can be explained by the methodological variations applied to the present tennis paradigm. Specifically, for the tennis task a ball machine was employed rather than the ball being fed by hand. This could to have rendered the flight path of the ball more predictable allowing participants to track it more efficiently. This is supported by the finding that the QE (i.e. tracking gaze on the ball) predicted tennis accuracy performance. Furthermore, the tennis players recruited for this study were club players who engage in weekly competition and scores on the FTF were generally higher in this study than Chapter 3 indicating a higher baseline index of resistance to distraction (i.e. FTF). It is highly possible that for confirmed tennis players the QE and its Offset, are better predictors of tennis performance under pressure than the FTF and future research should disentangle this.

The current study adds to the findings of Chapter 2 which showed that computer-based inhibition training could lead to enhanced inhibitory control and improved tennis volley performance. Participants who engaged in inhibition training were better able to inhibit the action of glancing at the target while (or before) making contact with the ball. The current results show that by training additional shifting and updating functions of WM, it is also possible to extend functional attentional control on the tracked target (the ball) via a delayed QE offset. Additionally, while the inhibition training task adopted in Chapter 2 included task-relevant search items (i.e. tennis balls in an array of other spherical items), the training task in the current study was both multi-modal (visual and auditory) and not sport specific. These findings therefore provide stronger support for a generic effect of WM training on the functions of attentional control that are important in sport settings, and as such, have important theoretical and practical implications.

First, the present results support the predictions of ACT (Eysenck et al., 2007) that worrying about performance disrupts task execution by reducing WM capacity and increasing bottom up processing. Similar levels of worry were reported by both groups, but the impact this had on processing efficiency was greater for the control group; who were unable to achieve the levels of extended attentional control (later QE offset) and performance effectiveness of the trained group when under pressure. As research suggests that negative thinking related to distraction tends to be more common than any other thought category among elite performers in high-pressure sporting contexts (Oudejans, Kuijpers, Kooijman, & Bakker, 2011), future research should investigate the potential efficacy of cognitive training methods specifically designed to target sports-related negative thinking and cognitive biases. Such research would support the refinement of a new development of ACT specifically for sport (ACTS; Eysenck & Wilson, 2016), which considers the influence of the performer's interpretation of the pressurised situation on subsequent attentional control.

Second, while it is important to acknowledge that the claims for the utility of so-called brain training (neuro-doping) devices for sport outstrip the evidence for their generic far-transfer benefits (see Simons, Boots, Charness, Gathercole, Chabris et al., 2016, for a critical review and commentary), the findings of the current paper suggest that specific far-transfer – to WM intensive, pressurised environments - is achievable. The empirical evidence therefore supports ACT's theoretical predictions for a moderating role of attentional control, revealing exciting implications for training in sport and other domains where motor performance must be accurate under pressure (e.g. military, surgery, aviation, etc.). Specifically, it may be possible for generalizable cognitive training to benefit performance under pressure in a range of related skills, rather than each skill requiring targeted training based on specific expert models (cf. quiet eye training; Vine et al., 2014).

Whilst the present results are highly encouraging the current study comprises several potential limitations which could be addressed in future studies. Cognitive and field performance was assessed immediately following the completion of the training period and it remains unclear whether the training effect observed is sustainable over time. Future studies could include a delayed retention test occurring several weeks after training (cf. Miles et al., 2015). Additionally, future research could also monitor players' tennis performance during competitive games to determine if effects transfer to the 'real world' (cf. Vine et al., 2011). Furthermore, whilst the tennis players recruited for the present study were experienced club players who engage in regular competitive activities they can still be considered as recreational players. With research showing that expert performance can be mediated by individual differences in WMC (Furley & Wood, 2016; Buszard & Masters 2017) future research should therefore aim to test the efficacy of cognitive training on elite / professional tennis players. There are also potential limitations with the design of the active control group task, despite its use in previous research (Owens et al., 2013) and its ability to control for any confounding effect of time exposure to a computerised task (Shipstead, Lindsey, Marshall, & Engle, 2014). First, as the level of difficulty did not increase during training, performance accuracy could not be meaningfully compared to the adaptive n-back group. Additionally, it is possible that performing the same 1-back task for 10 days was demotivating and this could explain the performance differences in post-training conditions. However, as performance on the 1-back task was maintained throughout training, and there were no group differences in far transfer performance in the post-training, low-pressure condition, this explanation is unlikely. Finally, a stronger conclusion for the benefits of WM training to performance under pressure could potentially have been made if both groups had undergone a pre-training pressure test. However, as in previous research testing the efficacy of training on performance under pressure (e.g. Ducrocq et al., 2016; Moore et al., 2012; Vine & Wilson, 2011) concerns related to repeated exposure to pressure manipulations was a more pressing concern.

Last but not least, whilst transfer effects off attentional control training were observed on the QE offset in tennis, more research is needed to establish with certainty whether the QE is indeed a sensitive index of attentional control in sports. Recent research has started to examine the influence of errors on QE duration (Walters-Symons, Wilson, & Vine, 2017), and combining electrophysiological measures will extend our understanding of how attention is influenced by pressure and errors in real-world environments, like sport. Under such circumstances it seems pertinent and imperative that future research examines the neural correlates underlying emotional responses to errors as revealed in relevant indices of attentional control. For example, examining the event-related potential (ERP) of the ERN which reflects error monitoring and has been theorized to reflect an emotional response to errors (e.g. Luu, Tucker, Derryberry, Reed, & Poulsen, 2003) which can be enhanced by WM training (Horowitz-Kraus & Brenitz, 2009), could be used to isolate the neural pathways explaining transfer related gains to the QE.

3.2.4.2 Discussion of the Findings Relating to the Dart Task

A secondary aim of the study was to address whether training would transfer to performance on a self-paced dart task which was not within the area of expertise of the tennis players recruited for the study. Results indicated that tennis players allocated to the training group did not display any benefits of training to dart throwing performance (i.e. accuracy) and that the QE duration did not predict dart throwing accuracy. A potential explanation could be that, whilst participants were generally able to hit the target consistently, they were not accurate enough to reliably throw darts in the vicinity of the bull's eyes with performance on the task showing high within participant variability.

Nonetheless, results revealed transfer of training on the QE in darts with participants allocated to the training group showing longer QE durations than their control group counterparts during the pressure dart task. The fact that training lead to improved attentional control in this self-paced task but did not result in actual performance improvements could be explained by one of the principal assumption of ACT (Eysenck et al., 2007) Specifically, ACT stipulates that anxiety usually impairs processing efficiency to a greater extent than performance effectiveness (i.e. performance on the task). Since the working memory training task did specifically target processing efficiency of WM, it is not entirely surprising to have only observed benefits of training on an index of attentional control but not on actual performance (i.e. performance effectiveness) in a sample that solely comprising of inexperienced dart players.

Furthermore, this finding is also consistent with previous research exploring the effect of pressure on dart performance in novice dart players. Specifically, Cañal-Bruland et al. (2010) demonstrated that anxiety had no effect on performance accuracy but that participants generally reported much greater mental effort whilst performing under pressure. Nibbeling et al. (2012) also demonstrated that participants tended to applied higher level of cognitive effort when performing a dart throwing dart under pressure which is consistent with ACT's prediction that anxiety tends impairs processing efficiency to a greater extent than performance effectiveness. The present results are also in line with recent findings which suggest that the QE may represent an index of mental effort (Walters-Symons, Wilson, & Vine, 2017). Finally, these results are also consistent with previous training research exploring the impact of QE training on Basketball players being testing on a non-trained dart task (Riehnoff et al., 2013). Specifically, in this study the authors showed that QE training could only transfer to some aspect of performance in a dart task in which participants were not experts.

3.2.5 Conclusion

To conclude, the present results lead the way for future research to further explore the potential application of cognitive training methods in improving processing efficiency of WM and attentional control. WM training led to enhanced WM capacity (near transfer) and improved ability to maintain effective attentional control and subsequent tennis performance under pressure (far transfer). The strength of the findings - when compared with much of the neuro-training literature - emanate from the focused empirical test of theoretically developed predictions about the influence of worry on specific functions of WM (ACT, Eysenck et al., 2007; ACTS, Eysenck & Wilson, 2016). As such, the potential practical significance of the findings can be targeted towards far transfer to sporting or non-sporting domains where complex and fine movements are performed under elevated levels of pressure.

Chapter 4

Using Attentional Bias Modification as a Training Tool to Improve Tennis Performance

4.1 Overview of the Chapter

Chapter 2 and 3 employed lab based cognitive training paradigms which were designed to directly target attentional control mechanisms and processing efficiency of WM. In both chapters results showed beneficial effect of training on performance under pressure. However a large body of research has provided evidence that attentional biases to threat tend to play a central role in the maintenance and development of anxiety symptoms and have been theorised to possibly mediate the anxiety-performance relationship in sports (ACTS). For example, research employing the attentional bias modification paradigm (ABM), a training method initially developed to target anxiety symptoms in clinical and non-clinical populations (Macleod & Clark, 2015), has shown a clear link between attentional biases and anxiety. In sports, research is beginning to explore the idea that cognitive biases can influence the negative impact of pressure induced anxiety on sports performance (Eysenck & Wilson 2016). Using a novel sports specific ABM training task, Chapter 4 explored whether training tennis players to either attend to negative or positive stimuli in a single training session, would result in transferrable effects on a dot-probe task designed to index attentional biases in sports, as well as sports performance outcomes. Indices of attentional bias, as well as performance and objective gaze indices of attentional control in a tennis volley task were assessed in pre- and post-training testing sessions with pressure being manipulated.

4.2 *Experiment 5: Using Attentional Bias Modification as a Training Tool to Improve Tennis Performance*

4.2.1 Introduction

In competitive sports, the ability to sustain optimal performance under high levels of pressure is often what differentiates success from perceived failure (Jones, 1991). A large body of research has emphasised the link between anxiety and performance impairments in both cognitive and sporting tasks because anxiety can impair attentional control needed for efficient task performance (see Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan & Eysenck, 2009; Eysenck & Wilson, 2016 for reviews). According to the attentional control theory of anxiety (ACT; Eysenck et al., 2007) experiencing elevated levels of anxiety impairs the efficient allocation of attentional control in goal directed tasks via its adverse effects on executive functions of working memory such as inhibition and shifting.

ACT argues that anxiety related disruptions to the switching function tend to reduce the ability to effectively switch attentional focus from one task to another, whilst disruptions to the inhibition function result in attentional resources being redistributed to distracting or task-irrelevant stimuli, such as worrisome thoughts about performance. This is especially relevant when individuals are faced with threat related stimuli since these kinds of stimuli have been shown to increase bottom up processes of attention usually recruited for threat detection at the expense of top down processes necessary to maintain adequate levels of attentional control to achieve task goals (see Berggren & Derakshan, 2013 for a review). There is some support that impaired inhibition of external and internal threat cues may mediate the anxiety-performance relationship in sport settings. For example, Wood and colleagues showed that football (soccer) penalty takers spent more time fixating the (threatening) goalkeeper and less time fixating their target aiming areas of the goal when under pressure (Wood, Vine, & Wilson, 2009). In addition, this effect was more pronounced when the goalkeeper actively used distracting behaviours (Wood & Wilson, 2010). Englert and Oudejans (2014) also revealed that an inability to inhibit internal sources of threats also tend to influence performance in sports settings. Indeed the authors showed that self-reported levels of distraction and an inability to inhibit distracting thoughts or worries relating to poor performance mediated the negative effect of anxiety on the performance of tennis players undertaking a serving task.

Consequently, one of the principal tenets of ACT stipulates that elevated levels of anxiety are generally associated with the manifestation of attentional biases directed towards threat-related stimuli, which is typically reflected by a tendency for anxious individuals to preferably attend to threatening stimuli relative to neutral or positive ones (i.e. impaired inhibition), whilst also displaying delayed attentional disengagement to this type of stimuli (i.e. impaired shifting function). A growing body of sport research has utilised gaze indices to objectively measure disruptions in goal directed attentional control and the influence of increased stimulus driven control. For example, the Quiet Eye (QE; Vickers, 1996), defined as the length of a final fixation or tracking gaze towards a relevant target prior to the critical phase of a goal-directed movement, is attenuated when under elevated levels of pressure. This effect has been shown in both self-paced (e.g. golf putting, Vine, Lee, Moore, & Wilson, 2013; basketball free-throw shooting, Wilson, Vine, & Wood, 2009, Nibbeling et al., 2012), and interceptive (e.g. shotgun shooting, Causer, Holmes, Smith, & Williams, 2011) sporting tasks, with reductions in the duration of the QE also negatively affecting task performance.

A recent extension of the original ACT adapted to sports (ACTS; Wilson & Eysenck, 2016), maintains that anxiety-induced attentional control disruptions influence performance effectiveness (as in ACT). However, ACTS focuses more on why sports performers might get anxious in a pressurised competitive environment in the first instance, and draws on Berenbaum's two-phase model of worry (Berenbaum, Thompson, & Pomerantz, 2007) to explain how cognitive biases may be a key factor in the development of competitive anxiety. Berenbaum suggests that anxiety (and its cognitive component worry) is influenced by the perceived *probability* and perceived *costs* of future undesirable outcomes. In sporting contexts, errors are an undesirable outcome, and the costs of errors are greater in high-pressure situations than low-pressure ones because more is at stake.

Furthermore, the perceived probability of errors increases as a function of the number of failures experienced during a match or competition and decreases as a function of the number of successful experiences.

Consequently, Eysenck and Wilson (2016) stipulate that negative cognitive biases generally contribute to an athlete's perceived evaluation of the potential costs and probability of not performing effectively. Specifically, an increased 'negative' attentional bias might cause a performer to pay more attention to perceived threat cues (e.g. the difficulty of the challenge they are facing, errors they have made, good performance from an opponent), whereas an interpretive bias might cause a performer to interpret errors as having an impact on how they will perform subsequently (e.g. I missed therefore I am not playing well today). The result will likely be an increase in individuals' level of error or action monitoring, which will disrupt the evaluative component of performance monitoring (e.g. Aarts & Pourtois, 2012) and plays a significant role in the experience of pressure for sports performers (e.g. Nicholls, Holt, Polman, & James, 2005).

Importantly, ACTS also states that a neutral (not selectively attending to perceived threat) or a positive bias (selectively attending to positive stimuli) should benefit performance by encouraging a challenge evaluation of the competitive context and reducing perceptions of the costs of failure (Eysenck & Wilson, 2016). For example, Hill et al. (2010) explored the impact of cognitive biases on competitive field performance of elite golfers who were notorious for either regularly choking or thriving when confronted with high levels of pressure. Results demonstrated that those who were able to maintain high levels of performance under pressure generally displayed more positive cognitions than those who frequently choked whilst reporting an increase in perceived control, decreased levels of evaluation apprehension as well as reductions in performance expectations. In contrast those who had a tendency to choke under pressure reported being highly self-critical of poor performance whilst demonstrating high levels of evaluation apprehension and a reduced ability to control their cognitions.

One popular paradigm that has been widely used in the field of cognitive and affective neuroscience to assess attentional biases to threats in anxious individual is the dot-probe task, originally developed by MacLeod, Mathews, and Tata (1986). The dot probe task indexes attentional distribution between simultaneously presented pairs of stimuli which differ in emotional valence, (e.g. happy faces or angry faces). Specifically, this task requires participants to swiftly discriminate the identity of a target probe that replaces one of the original image cues. An attentional bias to threat is usually reflected by a propensity to respond to a probe presented in the prior location of a threatening cue more rapidly than a positive or neutral one. A large number of studies have been conducted employing this paradigm and have contributed to establish that higher levels of anxiety are generally associated with an inclination to preferably allocate attention toward threatening stimuli (see Bar-Haim et al., 2007 for a review).

Based on these findings, the attention bias modification (ABM) paradigm has been employed to attempt to modify cognitive biases towards threats (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker 2002; Linetzky , Pergamin-Hight, Pine, & Bar-Haim, 2015). ABM paradigms are based on the original dot-probe task but differ in that they always contain a contingency where a successful response is always related to individuals allocating attention away from a negative stimulus whilst being encouraged to selectively attend to a positive or a neutral stimulus. There is some support for the efficacy of ABM training in both emotionally vulnerable populations (Notebaert, Clarke, Grafton, MacLeod, 2015; Macleod & Clarke, 2015) and in individuals performing under pressure (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002; Eldar, Ricon & Bar-Haim, 2008).

The Current Investigation

Based on ACTS' argument that displaying either a negative or positive bias may inversely affect sports performance under pressure, the present study was designed to assess whether inducing a positive or negative bias using a tennis-specific ABM dot probe training task could influence performance on a sporting task under pressure. Specifically, the present experiment explored tennis performance on a volleying task while also assessing an objective measure of attentional control (QE; see Chapter 2 and 3). It was hypothesised that the positive bias induced group would show a preference for positive tennis stimuli in the dot-probe task (i.e. show a positive bias) and reveal optimal QE durations and superior performance on a subsequent tennis task following the ABM intervention. Alternatively, the participants allocated to the negative bias induced group were predicted to show a preference for negative stimuli on the dot probe task, and show attenuated QE and poorer performance on the subsequent tennis task. Finally, it was further predicted that those who trained towards a positive bias would be less influenced by a negative interpretation of an error than the negative bias group and would be less likely to follow an error with subsequent error and would also display longer QE period on trials that followed and error.

4.2.2 Method

Participants

Participants were recruited from an opportunity sample of club tennis players who engaged in competitive tennis activities between one and three times per week at a North London based Tennis Club. The sample comprised 30 participants (25 males, 5 females; *M* age = 34.46 years, range: 16 to 55). An a priori power analysis (G*Power; Faul, Erdfelder, Lang, & Buchner, 2007) showed that based on the effect size of $\eta p^2 = .28$ observed on the QE in Chapter 3’s working memory training study, 26 participants were considered sufficient to achieve a power of 0.85 in an *F* test, given $\alpha = .05$. Thirty tennis players were however recruited to account for drop outs and potential loss of gaze data, which can occur when employing portable eye tracking equipment. Participants were randomly allocated to a positive or negative bias modification group but remained naïve to the purpose of the training stimuli. Ethical permission was obtained prior to the study by the Birkbeck College ethic board. All participants provided written informed consent and were debriefed at the end of the experiment.

Materials and Stimuli

Dot probe attentional bias assessment task. A tennis specific dot-probe task based on the original dot-probe task originally developed by Macleod et al.

(1986) was designed for this study. The task included images of famous tennis players displaying either negative or positive emotions during a tennis game. The dot-probe task was designed and presented employing the E-prime software and delivered on an HP Pavilion 15inches laptop set at a resolution of 1024 × 768 (refresh rate 65 Hz). For both pre and post tasks, 16 images representing eight famous tennis players displaying either positive or negative emotions were employed. All pictures were taken from matches at the Wimbledon Championship (England, UK) to ensure that all players were wearing white clothing and that the pictures' backgrounds were similar in each case. The pre and post tasks comprised of a different set of pictures resulting in 32 images (16 positive and 16 negative) being selected. In addition to the images selected for the assessment task another 12 images were also included for use in the ABM training task.

Prior to the study, twenty club tennis players who did not take part in the study rated twenty 'positive' and twenty 'negative' images for valence and arousal on a continuous scale ranging from 1 to 10 (one being the most negative and 10 being the most positive). Results showed a significant difference in ratings between positive and negative images in terms of valence $t(19) = 18.68$, $p < .001$, (positive images, $M = 8.00$, $SD = .89$; negative images, $M = 2.9$, $SD = .91$). There was no significant difference in reported arousal between the positive and negative images $t\ (19) = -1.06$, $p = .30$ (positive images $M = 5.88$, $SD = 1.22$; negative images $M = 6.53$, $SD = 1.86$).

Each trial of the dot-probe task began with the presentation of a fixation cross which lasted for 500ms. Two images were then presented simultaneously for

700ms with one of the images representing a famous tennis player expressing a positive emotion and the other showing a player expressing a negative emotion. The images were 5 cm in width and 6.5 cm in height, and were spaced 2 cm apart along the vertical axis, while being positioned centrally on the horizontal axis (see Figure 4.1). After 700ms both images disappeared and one was replaced by a small circle (i.e. a probe). Participants were required to identify as fast and as accurately as possible which image the probe replaced by pressing the ‘k’ key when the probe appeared behind the top picture, or the ‘m’ key if the probe appeared on the bottom. On 50 percent of trials the probe replaced a positive image whilst on the other 50 percent of trials the probe replaced a negative image. Both pre and post dot-probe bias assessment tasks comprised of 96 trials which were divided in 3 block of 32 trials. In each block, positive and negative images of all tennis players were presented twice with the order of presentation being randomised across trials. This ensured that image pairs representing negative and positive emotions were always different across all trials.

Figure 4.1*: Example of a dot probe trial showing a tennis related negative and positive picture.*

Attention bias modification training task (ABM). The ABM *training* task was based on the dot-probe attentional bias assessment task (described above). However, in order to ensure that participants selectively attended to pictures of either negative or positive valence, a contingency was introduced between probe position and the position of each of the valence images, with probes always appearing in place of a positive image for the positive group and probes always appearing in place of a negative image for the negative group. The ABM task comprised of a total of 24 tennis images (12 positive and 12 negative) with images employed for this training task being different to those used in the post training dot probe task. As with the initial attention bias assessment task, player's identity and the type of emotions displayed were randomised across trials so the same pair of images was never presented in succession. As in previous research by Notebaert et al., (2015), the ABM training task comprised a total of 384 trials, which were divided into 12 Blocks of 32 trials.

Tennis volley task. The tennis task was the same volley task employed in Chapter 3. The tennis volleying task included twenty trials, divided into two blocks of ten forehands and ten backhands. A set of ten Dunlop Fort All Courts balls and was employed for the duration of the study with participants using their own racquets. As in Chapter 3 the balls were delivered from a ball machine (Tennis Tutor Tennis Cube), placed centrally below the target and against the wall. All settings in terms of the position of the machine were identical to the settings used in Chapter 3

Measures

State anxiety. As with chapter 2 and 3, cognitive state anxiety was assessed employing the Mental Readiness Form (MFR-3; Krane 1994) Participants completed the MRF-3 at two time points in each condition: before the first block of ten volleys, after the first block of ten volleys (midway). As in previous studies testing the predictions of ACT (Vine et al., 2011; Wilson, Vine et al., 2009), only the cognitive anxiety subscale (an 11-point Likert scale anchored between 'not worried' and 'worried') was analyzed. A mean of the two values for each condition was used in subsequent analyses.

Attentional control scale (ACS). The Attentional Control Scale (ACS; Derryberry & Reed, 2002) is a self-report questionnaire which measures individual differences in attentional control. The ACS comprises of 20 items, which measures one's ability to focus perceptual attention, switch attention between tasks, and flexibly control thought. The items are scored on a 4-point Likert-scale, ranging from 1 (almost never) to 4 (always). Internal consistency of the ACS was shown to be good (Cronbach's α = .88; Derryberry & Reed, 2002). The ACS was completed prior to both tennis sessions.

***Attentional Bias Index (ABI*).** An attentional bias index (ABI) was computed for pre- and post-training dot-probe tasks following the methods employed by Notebaert et al. (2015). Reaction times on trials in which the probe replaced the positive image were subtracted from reaction times on trials in which the probe replaced the negative image. A negative ABI score thus reflected a negative attentional bias towards negative images whilst a positive score represented a positive bias.

Tennis volley performance.

Tennis errors and recovery index (ERI). Performance was evaluated in terms of the percentage of errors made by each participant (i.e. shots missing the target completely). Such 'misses' reflect examples of poor performance and are more likely to occur under competitive pressure (Vine et al., 2013). In order to test the predictions of ACTS, an error recovery index (ERI) was computed to reflect how players performed following an error. Here we recorded for each participant the total number of times an error was followed by another error on the volleying task with a lower score reflecting better recovery following a missed shot.

Tennis accuracy. Accuracy was calculated by determining where the ball bounced within the scoring rings on the archery target, from post-test analysis of video footage. Accuracy scores for each shot ranged from 0 to 10 with 0 being a miss (ball landing outside the target) and 10 being scored when the ball hit the centre area of the target.

The Quiet eye (QE). A 'Pupil Lab' head mounted eye tracker (https://pupil-labs.com) was employed to record and measure momentary gaze. As in Chapter 2 and 3, video data from the mobile eye tracking glasses and external camera were analyzed using Quiet Eye Solutions software (www.QuietEyeSolutions.com)(See General Introduction).As in previous chapters, the QE period for the tennis volleying task was operationally defined as the final tracking gaze on the ball prior to the initiation of the forward swing of the racquet. The analysis however included two QE measures. First, an average QE period was calculated from all trials. Second, the average QE period for trials that solely followed and error was calculated to specifically explore the incidence of attentional control after an error.

Procedure

The design of the experiment followed a pre-intervention (dot-probe and volley tasks), intervention (ABM training), post-intervention (dot probe and volley tasks) format. Participants were tested individually and arrived at the testing venue (a squash court at the Tennis Centre), to first perform the attention bias assessment dot- probe task. This task started with a brief training block containing 12 trials, followed by the 96 test trials. Participants were then fitted with the eye-tracking equipment, which was calibrated using a semi-automatic 6-point calibration procedure, before being asked to complete the MRF-3 before starting the tennis volley task. Participants undertook a short practice session (five backhands and five forehands) on the tennis task in order to warm up and get familiar with the speed of the ball delivery and the wearing of the eye tracker (pressure was not manipulated). Participants were asked to stand with both feet on a designated line whilst keeping a steady ready position, holding their racquet with both hands at around waist height.

Following this practice block, pressure was manipulated. Participants were told that tennis experts would use the external video data to compare their technique to other participants but also analyze their facial expression during the task, to heighten awareness of the self. Participants were also told that a ranking system based on their tennis accuracy scores was in place. Non-contingent feedback was provided, with participants being informed that their scores from their previous tennis performance (i.e. practice) would put them in the bottom 30% of the pool of participants already tested. They were in turn told that should their performance stay at this level their data could not be used for the experimenter's PhD study.

Before the first block of ten volleys, participants completed the MRF-3, which was completed again before the second block of ten volleys. Upon completing the first tennis task participants removed the eye tracker and performed the ABM training task, which lasted for 24 minutes. Participants then completed the second assessment dot-probe task and were refitted with the eye tracker and completed the second volley task. This was also performed under pressure using the same manipulation employed in the pre intervention tennis task.

Following the completion of the second tennis task, all participants were asked to complete another 5 forehands and 5 backhands (i.e. calibration session). The experimenter told participants that this additional session would help to check the quality of the calibration of the eye tracking recording device. Participants again reported their state anxiety levels using the MRF3. Along with the practice session this task was not performed under pressure providing the opportunity to assess the success of the anxiety manipulation. Upon completion of this last tennis task participants were debriefed and given a £25 compensation for 2 hours of experimental participation.

Data analysis

Because we were principally interested in the potential effect of ABM training on tennis performance under pressure, our tennis dependent variables (ABI scores, ACS scores, Tennis Errors, error recovery index, Tennis accuracy, QE) were subjected to 2 Group (positive vs. negative ABM training) x 2 Time (Pre vs. Post training) mixed analyses of variance. Linear regression analyses were also conducted to assess whether the QE predicted tennis performance (total percentage of errors aggregated across pre and post intervention testing sessions and accuracy scores). Finally in order to assess whether the pressure manipulation was successful for the tennis task, MRF-3 data were subjected to a 2 Group (positive vs negative ABM Training) x 4 Time (Practice [no pressure], Pre-training [pressure], Post-training [pressure], and final Calibration[no pressure]) mixed analyses of variance.

4.2.3 Results

Attention bias modification (ABM) training performance. Participants in both the negative and the positive group performed at high levels of accuracy (Positive Group: *M* = 98 %, *SD* = .01; Negative Group *M* = 99%, *SD* = .008) t < 1, indicating that participants in both group engaged with the requirement of the ABM task.

Dot-Probe Bias Assessment Task. An Independent samples t-test revealed no significant differences in ABI scores between the two groups in the pre testing session (Positive *M* = 14.09, *SD* = 22.91; Negative *M*= -2.03 *SD* = 31.79) *t* (28) = 1.67, *p* = 0.105.

Figure 4.2 shows pre and post Attention Bias Index (ABI) scores on the dot-probe task for both the positive and negative bias groups. ANOVA revealed no significant main effect of time, or group (*Fs* < 1). However, there was a significant Time X Group interaction, $F(1, 28) = 8.85$, $p = .006$, $\eta^2 p = .24$. This interaction was driven by a significant increase in ABI scores for the positive ABM group $t(14) = 2.39$, $p = .03$, (Pre $M = -2.03$, $SD = 22.91$; Post $M = 18.15$, $SD = 26.62$), compared to the negative ABM group who revealed a decrease in ABI scores between the two testing sessions, (Pre $M = 14.90$, $SD = 22.91$; Post $M = 2.93$, $SD = 25.54$), $t(14) = 1.76$ $p = .09$.

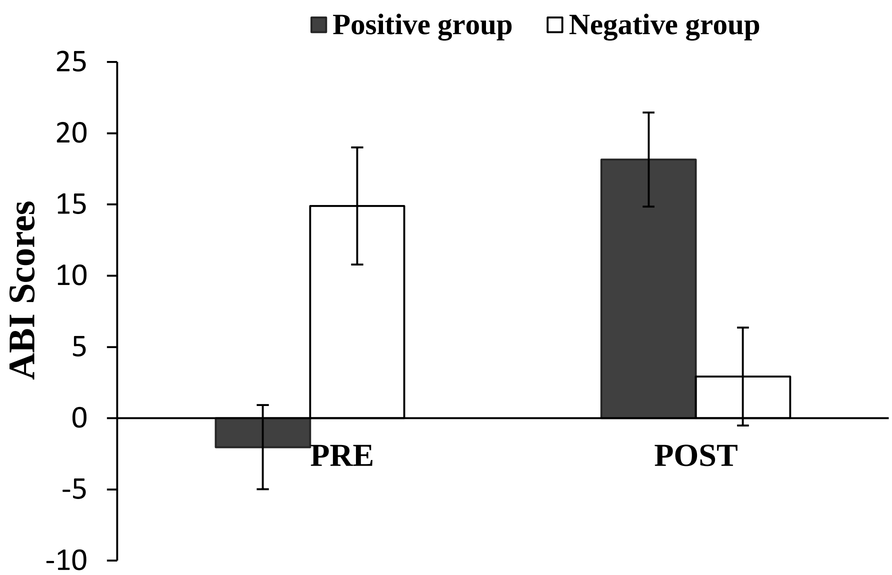


Figure 4.2: *Pre and post training mean (SEM) ABI score in milliseconds on the dot probe task for negative and positive groups.*

Cognitive Anxiety. A 2x4 ANOVA revealed a significant main effect of Condition, $F(3, 87) = 48.42$, $p <.001$, $\eta^2_p = .62$. Participants reported significantly higher levels of cognitive anxiety in the Pre high pressure ($M = 4.00$, $SD = 1.52$) session compared to the initial practice session ($M = 2.23$, $SD = 1.00$), $t(29) = 7.17$ $p < .001$. Participants reported significantly higher levels of cognitive anxiety in the

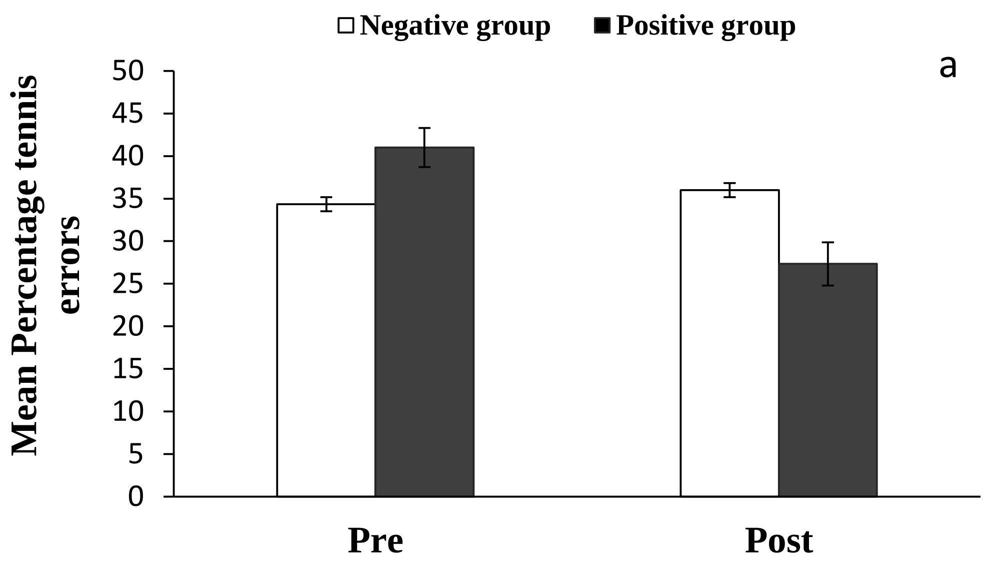
Post high pressure (*M* = 3.93, *SD* = 1.51) sessions compared to the final calibration session (*M* = 1.8, *SD* = .88), $t(29) = 9.13$ $p < .001$. This indicates that the pressure manipulation was successful in both sessions. There was no main effect of Group, nor a Condition x Group interaction, *Fs* < 1, reflecting that both positive and negative ABM groups reported similar levels of cognitive anxiety as a result of the pressure manipulation.

ACS (Attentional control index). ANOVA revealed no main effect of time nor a main effect of group or a Time X Group interaction (all *Fs* < 1). Scores on the ASC were comparable across the testing sessions for Negative group (Pre pressure *M* = 53.46, *SD* = 8.02; Post Pressure *M* = 52.60, *SD* = 6.85) and Positive groups (Pre pressure *M*=52.61, *SD* = 6.82; Post pressure *M* = 52.00, *SD* = 8.57).

Tennis Performance

Tennis errors. Volley error rates are presented in Figure 4.3a. Participants generally showed a decrease in the percentage of errors made on the tennis task from Pre (*M* = 37.66, *SD* = 18.37) to post training session (*M* = 31.66, *SD* =21.94). ANOVA revealed a significant main effect of time, $F(1, 28) = 8.38$, $p = .007$, $\eta^2 p = .23$. There was also a Time X Group interaction, $F(1, 28) = 13.68$, $p = .001$, $\eta^2 p = .32$. This interaction was driven by a significant decrease in the percentage of errors made by the positive ABM group, $t(14) = 4.63$, $p < .01$ (Pre intervention *M* = 41.00 %, *SD* = 17.64; Post intervention *M* = 27.33%, *SD* = 19.62), compared to the negative ABM group, who revealed no significant improvement between the two testing sessions (Pre intervention M = 34.33 %, SD = .19.07; Post intervention M = 36.00 %, SD = 23.91), $t < 1$. There was no main effect of group ($F < 1$).

Error recovery index. (ERI). ANOVA revealed no main effect for Group ($F < 1$), nor a main effect of time ($F < 1$). There was however a Time X Group interaction, $F(1, 25) = 4.88$, $p = .03$, $\eta^2p = .16$. This interaction was driven by a significant decrease in the number times an error followed an error by the positive ABM group, $t(12) = 2.372$, $p = .03$, (Pre intervention M = 3.64, SD = 3.04; Post intervention M = 2.07, SD = 2.13), compared to the negative ABM group who in contrast, revealed a pre to post non-significant increase in the number of times an error was made following an error on the tennis task (Pre intervention M = 3.07, SD = 3.04; Post intervention M = 3.64, SD = 3.47), $t < 1$. Error recovery index (ERI) data are presented in Figure 4.3b.



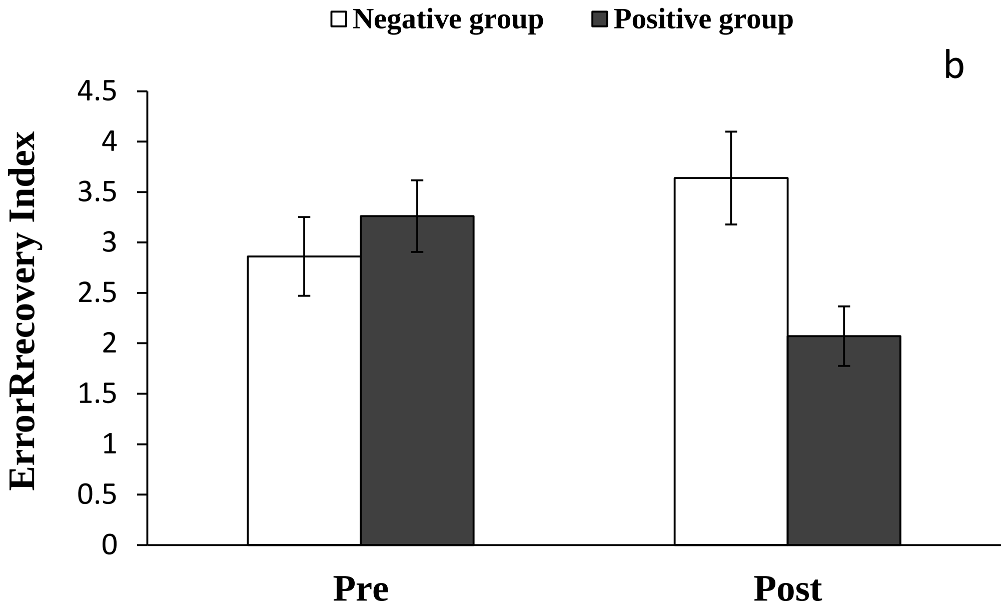


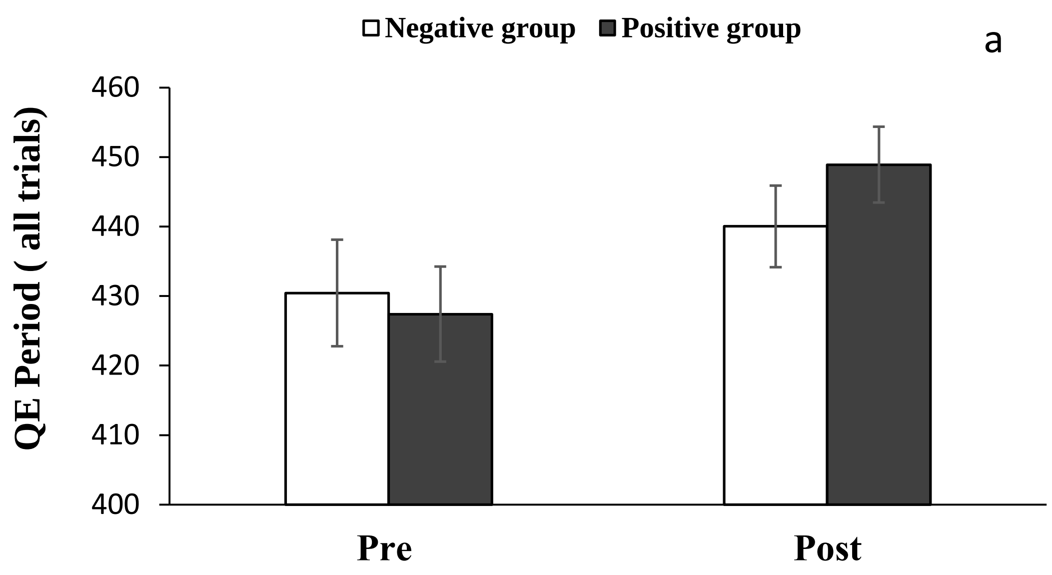
Figure 4.3: *Pre and post training (a) mean (SEM) percentage of errors made and (b) mean (SEM).) error recovery index, on the tennis volleying task for negative and positive groups.*

Tennis accuracy . A 2x2 mixed ANOVA with Group (Training, Control) and Time (Pre, Post intervention) revealed no significant main effect of Time, $F(1, 28) = 2.15$, $p = .15$, $\eta^2p = .07$, showing that accuracy performance did not significantly improve from pre ($M = 2.93$, $SD = .1.29$) to post ($M = 3.27$, $SD = 1.49$) intervention. There was no Time X Group interaction, 1.70, $p = .20$, $\eta^2p = .09$ or a main effect of group ($F < 0$).

QE Period (QE), calculated for all trials. Quiet eye duration data are presented in Figure 4.4a. 2.2% of trials across testing sessions were lost due to gaze not being registered. ANOVA revealed a main effect of time $F(1, 28) = 13.06$ $p = .001$. $\eta^2p = .31$, indicating that participants in both groups displayed longer QE duration in the Post-intervention session ($M = 446.15$ ms, $SD = 41.67$) than in the

Pre-intervention session (*M* = 426.15ms, *SD* = 52.80). ANOVA revealed no main effect of group, nor a significant Time X Group interaction (all *F*s < 1).

QE period for trials that followed an error . The analysis conducted on QE durations for trials that followed an error revealed no main effect of group, nor a main effect of Time, nor a Time X Group interaction (all *F*s < 1). (see Figure 4.4b)



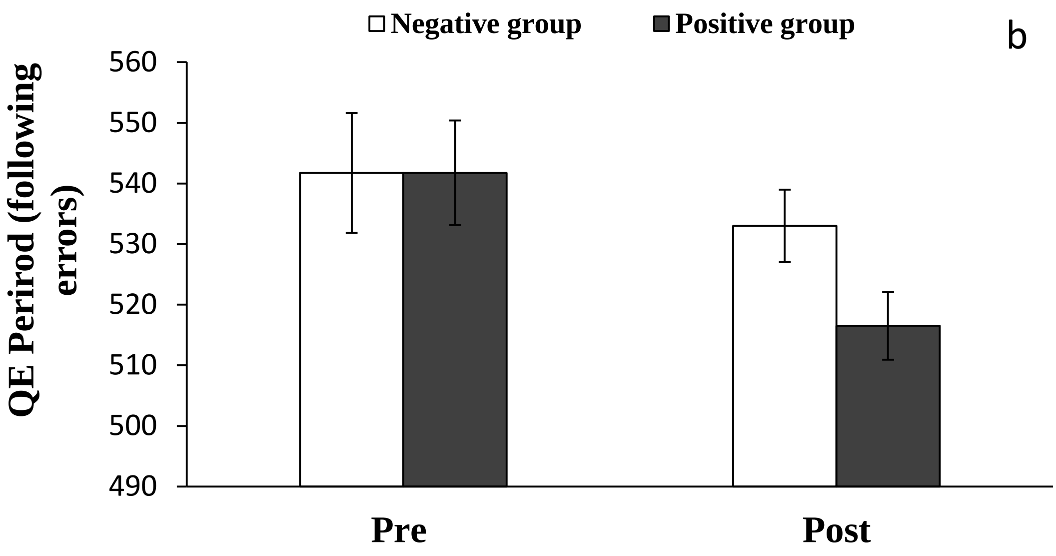


Figure 4.4: *Pre and post training (a) mean (SEM) QE durations (b) mean (SEM) QE durations after an error on the tennis volleying task for negative and positive groups.*

QE Onset (QE-ON). ANOVA revealed a significant main effect of time $F(1, 23) = 4.27$, $p = .05$, $\eta^2p = .12$ indicating that participant in both group displayed earlier QE onset in the Post-intervention session (M = 131.89 ms, SD = 34.62) than in the Pre-intervention session (M = 143.15 ms, SD = 31.86). ANOVA revealed no main effect of group, nor a significant Time X Group interaction (all Fs <1).

QE Offset (QE-OFF).ANOVA revealed neither a significant main effect of condition, nor a main effect of group, or a significant Time X Group interaction (Fs < 1).

Regression analyses conducted on the tennis scores obtained in the pre and post training session revealed that the QE significantly predicted 21% of the variance in tennis accuracy scores (R^2 = .21, β = .13, t = 3.93, p < .001) and that QE in turn predicted 34% of the variance. the percentage of shots not reaching the target (i.e. error rates) (R^2 = .34, β = - 127, t = - 2.83, p = .006).

4.2.4 Discussion

Based on recent application of ACT (Eysenck et al., 2007) to sports (ACTS; Eysenck and Wilson, 2016) underlining the potential implications of cognitive biases in predicting successful or impaired sports performance outcomes under pressure, the present study was conducted to assess whether inducing a positive or a negative bias in confirmed tennis players using a novel tennis-specific ABM intervention could influence their performance on a tennis volleying task performed under pressure. Specifically, it was predicted that that a ‘positive’ bias induced group would show a preference for positive tennis stimuli (i.e. show a positive bias) following the ABM intervention, whilst participants allocated to the ‘negative bias’ induced group would show a preference for negative stimuli. Furthermore, it was predicted that those who trained towards a positive bias would display superior performance on the tennis volleying task, would be less affected by errors than the ‘negative’ bias group and would demonstrate sustained performance on the volleying task following the commission of errors. A final hypothesis predicted that the ‘positive’ bias group would reveal enhanced attentional control as measured by the QE thought to reflect an objective gaze index of ‘field’ attentional control, whilst the ‘negative’ group would reveal impaired attentional control and a reduction in the length of the QE.

First, results indicated that the ABM training was successful in eliciting significant changes in the attentional bias of the different groups. Participants who were trained to attend towards positive images of tennis players, showed an increased bias toward such stimuli in the post testing session (i.e. increased positive bias). In contrast those who were trained to attend to images showing tennis players displaying negative emotions showed a decreased positive bias as measured by the ABI index (Figure 4.2). These results are in line with previous findings where ABM interventions successfully reduced attentional biases to threats in anxious (Hayes, Hirsch, and Mathews, 2010; Notebaert, & MacLeod Notebaert, Clarke 2016, see MacLeod & Clark, 2015, for a review) and non-anxious populations (MacLeod et al., 2002; Eldar et al, 2008).

Furthermore, as predicted by ACTS, ABM training affected tennis performance under pressure. Indeed those who trained to attend toward positive tennis images and away from negative ones displayed a significant reduction in the number of errors made on the tennis volleying task from pre to post intervention. In contrast, the performance of those who were trained to attend towards negative stimuli remained at a similar level of performance. It is noteworthy to point out that while pressure did not appear to cause a decrease in tennis performance (choking) for the negative bias group, it appears as if increased pressure reduced the potential learning effects that would be expected due to the post-testing condition always following the pre-testing condition in a short space of time (see Chapters 2 and 3). However, an alternative explanation for this finding may be that while the participants who received negative ABM training revealed a reduction in ABI score (Figure 4.2), this did not actually lead to an actual negative bias (i.e. an ABI score below zero). Future research needs to further explore the use of ABM training on sports people to assess whether truly negative biases can be created in a laboratory environment.

Importantly, the present investigations also assessed the impact of ABM training on response to errors under pressure, as this is a key prediction of ACTS. The experience of pressure is likely to vary during performance, and errors are an extremely salient source of information that could have potentially threatening consequences if perceived negatively. Results supported the hypothesis and revealed that the positive bias induced group displayed a pre to post decrease in the total number of errors that were made following the commission of errors which was not the case for the negative bias induced group who showed a general pre to post increase on the error recovery index (ERI). The findings on the error recovery index (i.e. the total number of errors made following an error on the tennis task) are also line with previous research testing the original predictions of ACT (Eysenck et al., 2007) and support the idea that impaired inhibition to external and internal threat cues may mediate the anxiety-performance relationship (Wood & Wilson, 2010; Englert & Oudejans, 2014). These findings are also in line with ACTS and further the idea that possessing a positive cognitive bias will potentially reduce the costs of making a mistake (Wilson & Eysenck, 2016). It is highly conceivable that the group differences observed in responses to errors following training may be related to differences in levels of error monitoring following the ABM intervention. Indeed, recent research by Nelson, Jackson, Amir, and Hajcak (2015) demonstrated that it was possible to train attention away from negative information using ABM interventions to reduce the 'error related negativity' (ERN), an event related potential thought to represent a neural index of error monitoring. Additionally, a recent meta-analysis (Moser et al., 2013) also revealed that cognitive anxiety is generally associated with enhanced ERN.

Although the present study did not adopt ERN methods, one of the aim of the study was to show that the performance effects found for ABM training would be mediated via objective attentional measures; QE (when measured for all trials and only for trials that followed an error). Results initially revealed that the QE duration was found to predict both tennis errors and accuracy scores. However, both 'positive' and 'negative' groups displayed similarly enhanced QE durations following the ABM training intervention reflecting potential learning effect or the allocation of more effort in the second testing session (see Walter-Symons, Wilson & Vine, 2017). A potential explanation for these findings is that either the QE was not a sensitive measure of improved attentional control in this task, or the significant performance effects of ABM were due to other psychological benefits.

First, it is interesting to note that the self-reported measure of attentional control – the ACS (Derryberry & Reed, 2002) – also failed to reveal significant changes after training. Additionally, while it was previously shown in Chapter 3 that the tennis volley QE was sensitive to working memory training, attentional bias training may not influence attentional control in the same direct way. Indeed the dual n-back training paradigm employed in Chapter 3 directly trained the efficiency of the principal executive function of WM thought to reflect attentional control. However ABM interventions have not been specifically designed to directly target such mechanisms but are useful to attenuate attentional biases to threats, which are believed to directly result from anxiety induced deficiencies in attentional control (see; Eysenck et al., 2007; Mogg, Holmes, Garner & Bradley, 2008). It is therefore not entirely surprising that the present results did not reveal any effects of ABM training on gaze indices of attentional control in sports (i.e. the QE) or on self-report measure of attentional control (i.e. ACS). Moreover, whilst recent research has shown that individual differences in attentional control can predict the magnitude of change in attentional bias following ABM training (Basanovic, Notebaert, Grafton, Hirsch & Clark 2017), another study showed positive effects of ABM training on eye tracking indices of inhibition (Chen, Clark, Watson, Macleod & Gustella, 2014). However, there seems to be a lack of theoretical consensus in the ABM literature about the specific mechanisms by which ABM training does lead to changes in attentional biases (Cisler & Koster, 2010) and it would appear that attentional control generally facilitates ABM induced change in attentional bias rather than directly target attentional control processes.

Second, it is possible that ABM acted more directly on emotion regulation strategies of the participants, rather than their levels of attentional control. Specifically, emotion regulations strategies are believed to moderate attentional biases towards threats (Cisler & Koster, 2010). Whilst attention control can be seen a regulatory ability that allows individuals to efficiently disengage their attention from negative stimuli, emotion regulation allows individuals to better cope with negative emotions. Specifically, emotion regulation has been argued to reflect the different processes by which individuals can directly command the types of emotion they have, when they have them and how they are expressed with attentional allocation having been proposed as one possible mechanism of emotion regulation (Koole, 2009). For example, employing such strategy, a sports performer may consciously direct his attention on past positive experiences during competition instead of allocating attention to worrisome thoughts relating to present performance to reduce negative impact of pressure. As such, the positive ABM group may have dealt with their heightened anxiety in a more positive way, possibly via positive mental imagery.

Indeed, it is possible that training to repetitively attend to pictures depicting tennis players displaying positive or negative emotions during a tennis match tennis may have encouraged or replicated emotional mental imagery, which could have influenced participants' pre-performance state. Mental imagery is a psychological training technique which has been shown to be effective in sports through positively impacting psychological states during performance, such as enhancing self-confidence, self-efficacy and concentration (Garza & Felt, 1998; Post & Wrisberg, 2012). Imagery training techniques are also thought to be highly beneficial when used as coping strategies to maintain existing skills but also assess and evaluate past performance (Thelwell & Maynard, 2002: White & Hardy, 1998).

Whilst the results presented above are encouraging, the present study comprises several limitations which could be addressed in future research. One limitation of the present study resides with the length of ABM training undertaken following the pre testing session, and this was chosen because a single session of ABM is generally more effective in reducing a negative bias than multiple sessions (see Macleod & Clarke , 2105 for a review). The present study only involved one, twenty-five-minute session of ABM. It is therefore maybe not entirely surprising that a sensitive gaze index of attentional control such as QE remained unaffected by ABM training and further research should aim to investigate the potential benefits of ABM training in sports employing lengthier training protocols.

It is also important to note that whilst benefits of ABM training on tennis performance were observed, participants allocated to the positive group did not report lower levels of self-reported anxiety nor did those allocated to the negative group report increased levels of anxiety. It would appear that whilst both 'positive' and 'negative' groups reported similar levels of state anxiety during the post intervention tennis task, participant who were trained to attend away from negative stimuli appeared to have been less affected by the negative impact of pressure than those who were trained to attend away from positive stimuli. These findings are in line with previous research that found no effects of ABM training on anxiety levels but better performance on a stressful task (Eldar, Ricon & Bar-Haim, 2008). Two other limitations of the research might explain this null finding. First, anxiety was only assessed at two time points, and in order to test the predictions of ACTS, it would be important to assess anxiety after each shot to see how anxiety is affected by the commission of errors (Eysenck & Wilson, 2016). Second, it is also possible that participants reported on the objective increase in the level of competitive pressure, rather than their anxiety per se, when responding using the single item MRF-3. Furthermore, whilst participants were allocated to their respective group using random sampling, results revealed (albeit non-significant) baseline differences in terms attentional biases between the two groups.

Lastly, whilst the QE has been shown to be a valid measure of visual attentional control in the sports field (Vine et al., 2013) it is highly possible that other neural processes are involved in development and maintenance of attentional biases that are not reflected by the QE. Indeed, ABM training may have had an indirect or a direct impact on other neural indices of attentional control and future research should investigate the link between attentional biases and neural mechanism of attentional control in predicting sports performance using electrophysiological measures.

In conclusion, results of Chapter 4 indicate that it is possible to improve performance on a sporting motor task performed under pressure following a single session ABM intervention, though future research should investigate the sustainability of improvement levels as the effect were short term performance improvements. The present results support important assumptions of ACTS. Indeed, training individuals to attend away from negative stimuli, and towards images of tennis players displaying positive emotions resulted in participants displaying a positive attentional bias and a reduction in the number of errors committed on a tennis volleying task. While the present experiment has not been able to confirm a definitive mechanism behind the transfer effects of ABM training on improved performance via change in attentional bias, results do show that participants' ability to cope with the commission of error was enhanced compared to participants who were trained to attend to negative stimuli. Such findings indicate that the ABM training intervention protected participants who trained to attend towards positive stimuli against the negative influence of anxiety. The findings of Chapter 4 have important theoretical implications and pave the way for way for future research to further explore the neurocognitive mechanisms by which cognitive biases may modulate motor performance when levels of pressure are elevated.

Chapter 5

Attentional Biases Influence Tennis Performance Under Pressure Via Impairments in Attentional Control: Evidence From Gaze and Neural Measures

5.1 Overview of the Chapter

The set of experiments conducted in Chapter 2 and 3 employed lab based cognitive training paradigms designed to directly target attentional control mechanisms and processing efficiency of WM. In both chapters results showed transfer of training benefits to both key gaze indices, and tennis performance under pressure, confirming the importance of maintaining sufficient levels of attention control to perform effectively under pressure. Results of the experiment presented in Chapter 4 demonstrated that it was possible to reduce attentional biases to threat in tennis players using a novel tennis-specific ABM training task. This reduced bias resulted in improved performance in a tennis volleying task and enabled participants to better cope with the commission of errors.

Whilst these findings confirmed the potential role of cognitive biases in potentially determining effective sports performance in anxiety provoking contexts, the benefits of ABM training were not modulated by either an objective (QE) or a self-reported (ACS, Derryberry and Reed, 2002) measure of attentional control. More research is therefore needed to further explore whether attentional biases can impact the anxiety-performance relationship via mechanisms related to attentional control. Specifically, the first aim of the experiment conducted in Chapter 5 was to verify the findings of Chapter 4 in terms of the implication of attentional biases in modulating performance on a tennis volleying task performed under pressure. The second aim of this study was to explore the neurocognitive correlates of error processing and cognitive control using the ERN and the N2 components of the ERP during a flanker task designed to challenge response inhibition. This would serve to verify whether the impact of attentional biases on tennis performance is related to impairments in attentional control and whether such association is in turn associated with impairments in attentional control in sports as measured by the QE.

5.2 *Experiment 5: Attentional Biases Influence Tennis Performance Under Pressure Via Impairments in Attentional Control: Evidence From Gaze and Neural Measures*

5.2.1 Introduction

The ability to perform when confronted with high-pressure and anxiety-provoking situations is essential for accomplishing and maintaining optimal levels of performance in sports (Bortoli, Bertollo, Hanin, & Robazza, 2012; Nicholls, Holt, Polman, & James, 2005). Given the ego-threatening nature of competitive environments, sports competitions are often experienced as high pressure-inducing situations. Pressure refers to various situational incentives to achieve high levels of performance and is generally associated with increased levels of cognitive anxiety (Baumeister, 1986; Englert & Oudejans, 2014). Recent research in sports psychology has shown that difficulties in attaining optimal levels of performance when competing under heightened levels of pressure are directly related to performers' inability to maintain sufficient levels of attentional control (Vine, Lee, Moore, & Wilson, 2013; Wilson, Vine, & Wood, 2009).

The attentional control theory of anxiety (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007) argues that anxious apprehension as well as worrying about performance outcome can disrupt the efficient exercise of attentional control, leading to increased distractibility by task-irrelevant stimuli and reduced processing efficiency. Specifically, anxiety has been shown to disrupt task execution by reducing working memory capacity and increasing bottom up processing (Eysenck et al., 2007; Derakshan & Eysenck, 2009). Nevertheless, despite its strong emphasis on the detrimental impact of anxiety on attentional processes, ACT also maintains that impairments in performance outcomes for anxious individuals relative to non-anxious individual are not always apparent. Specifically, ACT stipulates that anxious individuals tend to apply greater amounts of cognitive resources (i.e. mental effort) to attain comparable levels of performance outcome than their non-anxious counterparts.

Recent research has shown that the Quiet Eye (QE; Vickers, 1996), thought to represent an objective index of attentional control in many sporting disciplines, and defined as the final fixation or tracking gaze towards a relevant target within three degree of visual angle or less, could possibly serve to regulate the allocation of attention following the commission of errors in anxiety provoking contexts. Specifically, Walters-Symons, Wilson, and Vine, (2017) observed that golfers undertaking a putting task under pressure generally showed longer QE periods (i.e. higher levels of attention control) for holed putts that followed a missed attempt (i.e. an error) compared to putts that followed a successful attempt. Additionally, shorter QE periods were found on putts that were missed when following an error. In line with the original assumptions of ACT and ACTS (Eysenck & Wilson, 2016), these findings strongly suggest that a 'performance monitoring' system may be at play in regulating emotional responses to errors and to enable performers to rectify subsequent task performance. In addition, as theorised by ACT and ACTS, this finding suggests that when faced with elevated levels of pressure relating to making errors, athletes may resort to employ compensatory strategies such as applying higher levels of cognitive effort on their next attempt.

It has been shown that individual differences in levels of error monitoring can determine whether or not performers engaging in competitive activities are negatively affected by the experience of competitive pressure. For example, Nicholls et al. (2005) examined potential stressors in elite adolescent golfers over a period of one month, and found that the most frequently-cited stressors impacting upon performance were making physical as well as mental errors. Berenbaum, Thompson, and Pomerantz, (2007) have also suggested that the experience of competition related anxiety (and its cognitive component, worry) may be largely influenced by the perceived probability and perceived costs of impending undesirable outcomes. Indeed, in sports, errors are usually seen as an undesirable outcome, and the costs of making errors are generally greater in high-pressure situations than low-pressure ones because of the negative connotations of not performing well. ACTS (Eysenck & Wilson, 2016) consequently argued that the perceived probability of making errors in sports should increase as a function of the number of failures experienced during a match or competition, but in turn decrease as a function of the number of successful outcomes. Hence, if that is the case, then more 'anxious' or 'worried' sports performers should show higher levels of performance or 'error' monitoring during performance and display a more 'sensitive' performance monitoring system than less anxious or worried athletes. Importantly, ACTS also suggests that attentional biases (i.e. towards positive or negative emotional stimuli) may determine whether or not an athlete will engage in increased levels of performance monitoring, with individuals displaying attentional biases towards threat being more prone to worry about forthcoming or current performance.

A large body of research in the area of cognitive neuroscience proposes that the commission of errors tends to generate neural activity in the anterior cingulate cortex (ACC). Specifically, two event-related potential (ERP) components, the error-related negativity (ERN) and N2, have been suggested as reflecting performance or conflict monitoring when undertaking simple cognitive tasks such as the flanker or go/no-go tasks (Moser et al., 2013; Folstein & Van Petten, 2008). The idea being that being able to detect conflict during response selection (i.e. the simultaneous activation of incompatible actions), may act as an early warning mechanism of events in which errors are likely to be made (e.g. incongruent trials on a flanker task), signaling that increased levels of attention (i.e. effortful control) needs to be applied to avoid further errors.

The ERN is believed to represent neural signals observed in error processing, reflecting conflict between correct and the erroneous motor responses made when undertaking a cognitive task (Nieuwenhuis, Ridderinkhof, Blom, Band, & Kok, 2001; Steinhauser & Yeung, 2010). Consistent with the assumption that this specific ERP reflects an 'on-line error monitoring system', larger ERNs are generally associated with adaptive behavioural adjustments, such as slower and more accurate responses following errors in cognitive tasks (Compton et al., 2008). In addition, several studies have found that the ERN tends to be greater amongst individuals who are prone to display high levels of trait anxiety and trait worry (Hajcak, 2012; Moser, Moran, Schroder, Donnellan, & Yeung, 2013). Lastly, a greater ERN is also thought to represent heightened sensitivity to internal threats such as worries as well as reflecting compensatory effort amongst high anxious individuals (Moser et al., 2013).

As mentioned above, another ERP believed to reflect changes in the recruitment of cognitive control and compensatory effort in anxiety is the N2 (Yeung, Holroyd, & Cohen, 2005). Specifically, the N2 is thought to emanate from a group of ERP responses that are believed to be directly related to performance monitoring and cognitive control (Folstein & Van Petten, 2008) with a functional equivalence having been suggested between the stimulus-locked N2 and the response-locked ERN on high-conflict responses during cognitive tasks (Danielmeier et al., 2009; Yeung & Cohen. 2006). Specifically, the N2, which occurs over frontal midline regions at 200 to 350 ms following the onset of a stimulus, has been found to be greater under conditions of conflict, such as on incongruent trials in a flanker task or during tasks which necessitate the inhibition of prepotent responses (Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003; Van Veen & Carter, 2002a). The N2 is therefore thought to signal the degree to which higher order cognitive control resources (i.e. attentional control) are recruited to resolve potential conflict, allowing individuals to inhibit incorrect responses (Braver, Barch, Gray, Molfese, & Snyder, 2001; Jones, Cho, Nystrom, Cohen, & Braver, 2002). Thus, the N2 has been theorised to represent effortful control and individual differences in the ability to engage executive processes to inhibit dominant responses (Posner & Rothbart, 2007).

Importantly, a large body of research has suggested that, similarly to the ERN, the N2 is generated in the anterior cingulate cortex (ACC), which is believed to be sensitive to emotional and motivational factors (Bush, Luu, & Posner, 2000; Luu & Tucker, 2004). The ACC has also been demonstrated to be more active when individuals are required to process conflicts emanating from emotionally salient distractors compared to neutral stimuli (Bishop et al., 2004; Vuilleumier, Armony, Driver, & Dolan, 2001). This idea is consistent with one of the main precepts of ACT which denotes that individuals predisposed to show higher levels of anxiety tend to employ more cognitive resources to perform at comparable levels to their non-anxious counter parts.

For example, Dennis and Chen (2009) explored whether threat-related attentional deficits usually observed in anxiety, may relate to changes in cognitive control during task execution. Results showed that higher levels of trait anxiety were associated with greater N2 amplitudes during a flanker task involving the presentation of fearful faces. The authors argued that a greater N2 in anxious individuals may reflect a compensatory mechanism in response to potential attention interference by threat. Lamm et al. (2012) in turn found greater N2 activation in response to emotionally salient stimuli in comparison to neutral stimuli in the context of a go/no-go task. Finally, in a recent study, Owens, Derakshan and Richards (2015) employed a modified emotional version of the flanker task to explore whether trait worry would increase the processing of irrelevant distractors and result in greater recruitment of cognitive resources as reflected by a greater N2 under conditions of low and high WM load. Results indicated that trait vulnerability to worry was associated with a greater recruitment of the N2 when participants where actively engaging with the inhibition of distractors under high working memory load. The authors therefore explained that vulnerability to worry is directly related to reductions in attentional control.

Given the fact that competition between threatening and non-threatening stimuli appears to be necessary for a threat bias to emerge (Mathews & Mackintosh, 1998), the sensitivity of the N2 to conflict should also makes this ERP well suited to investigate whether attentional control does indeed mediate the negative impact of attentional biases to threat on sports performance. Furthermore, it is important to note that the research presented above strongly suggest that the application of compensatory effort reflected by a greater N2 in anxious or worried individuals may help them maintain satisfactory levels of performance in simple cognitive tasks such as a flanker where demands on cognitive resources tend to be low. However, it is highly possible that applying excessive levels of compensatory effort or effortful may be detrimental when undertaking complex visuomotor task performance if it leads to reinvestment (Masters & Maxwell, 2008). Indeed, in sporting pressurized contexts the tendency to reinvest, refers to a tendency by individuals to manipulate conscious, explicit, rule-based knowledge in working memory in order to control the mechanics of their movements during motor performance" (Masters & Maxwell, 2004). Importantly, reinvestment has been heavily linked to the choking phenomenon in sports (Masters & Maxwell, 2008)

As explained earlier, engaging in elevated levels of performance monitoring behaviours in sports should negatively impact performance by increasing worry levels. ACTS states that performers who display attentional biases to threat will be more likely to 'notice' physical and mental errors due to an enhanced attentional bias for threat cues. Results presented in Chapter 4 indicated that participants who had been trained towards a positive attentional bias by repeatedly attending toward positive tennis related images and away from negative ones (i.e. making negative or threatening stimuli less salient), generally made less errors on a tennis task when compared to participants who had been trained to repetitively direct their attention towards images of tennis players displaying negative emotions. Importantly, results also demonstrated that those participants who trained towards a positive bias, also showed a reduction in the number of errors that were made following preceding errors, indicating an increased ability to cope with the emotional costs of making mistakes under pressure.

The experiment presented in Chapter 4 did not however employ any direct measures of performance monitoring and results did not indicate that reductions in the number of errors observed following the commission of errors were mediated by longer QE duration (i.e. more effort). Whilst this finding may be related to the fact that both groups actually showed a positive bias following the intervention (albeit a relatively more negative bias for the negative group), it is highly possible that participants in the positive bias group were able to reduce the influence of negative performance monitoring, which could be possibly be related to a reduced ERN or N2. Indeed, recent findings in cognitive and affective neuroscience by Nelson, Jackson, Amir, and Hajcak (2015) have shown that it is possible to train attention away from negative information using ABM interventions to reduce the ERN.

The Current Investigation

Whilst technical limitations do not currently allow the direct assessment of neural indices such as ERPs during the performance of a live sporting task, we decided to assess if potential indices of 'attentional control' such as the ERN or the N2 obtained during a cognitive lab-based task were related to the experience of competitive pressure in sports. Additionally, whilst results of Chapter 4 showed that ABM training resulted in improved tennis performance on a tennis task as well as tennis players being less affected by the commission of errors, more research is needed to verify whether the relationship between attentional biases and tennis performance is associated with enhanced attentional control (i.e. either the QE or neural indices of attentional control).

The aims of the present experiment were therefore two-fold. The first aim of chapter 5 was to verify the findings of Chapter 4 in terms of the implication of attentional biases in modulating performance on a tennis volleying task performed under pressure. The second aim of this study was to explore the neurocognitive correlates of error processing and effortful control using the ERN and the N2 ERP components during a flanker task designed to challenge response inhibition, and verify whether effects of attentional biases on tennis performance may be related to neural processes relating to attentional control. A final aim of the study was to explore whether the relationship between attentional biases and performance was in turn related to impairments in attentional control as measured by the QE.

Specifically, it was predicted that levels of attentional bias towards negative stimuli would be related to tennis performance as measured by commission of errors and the ability to recover from such errors. It was further predicted that these relationships would be modulated by participants' levels of error or performance monitoring and effortful control when the exercise of attentional control processes are required for task performance (e.g. performance on incongruent trials requiring inhibitory control). Finally, it was further predicted that the QE (i.e. an objective index of attentional control in sports) would also be associated with levels of attentional biases and performance on the tennis task.

5.2.2 Methods

Participants

Participants were recruited from an opportunity sample of recreational club tennis players who engage in competitive tennis activities between 1 and 5 times per week at a London based Tennis Club. The sample included 35 participants (31 males, 4 females; *M* age = 32 years, *SD* = 10.42, range: 17 to 54). The average LTA (Lawn Tennis Association) tennis rating of the sample was 6.1 on a scale of 1.1 to 10.2, indicating that the sample comprised of experienced players. The size of the sample was based on previous research looking at correlates of cognitive control in anxiety by Dennis and Chen (2009) and Owens et al. (2015), who employed a sample of 36 and 31 participants respectively. According to David (1938) a sample size equal or superior to 25 suffices to conduct Pearson's correlations.

Materials and Stimuli

Flanker task. The flanker task employed in this study was a modified version of the Eriksen flanker task (Eriksen & Eriksen, 1977) which was designed and delivered using the E-prime software and presented on an Asus VG248QE 24 inches LCD Monitor with a resolution of 1920 x 1080 and a refresh rate of 60Hz. Participants were required to use the mouse left and right keys to respond to a centre (target) letter of a five-letter string in which the target was either congruent (e.g. MMMMM or NNNNN) or incongruent (e.g. NNMNN or MMNMM) with the distracter letters. For example, during the first block, participants were instructed to respond with a left-hand keyboard response if the target letter is M; a right-hand keyboard response was required for target letter N.

During each trial, flanking letters were presented 35 ms prior to target letter onset, and all five letters remained on the screen for a subsequent 100 ms (total trial time was 135 ms). Each trial was followed by a variable inter-trial interval (1,200–1,700 ms) during which a fixation cross was presented. Characters were displayed in a standard white font on a black background and subtended 1.38 of the visual angle vertically and 9.28 horizontally. All stimuli were presented using the E-Prime software to control the presentation and timing of all stimuli, the determination of response accuracy as well as the measurement of reaction times.

The experimental session included 480 trials grouped into 12 blocks of 40 trials during which accuracy and speed were equally emphasized. Across the entire task, the ratio of congruent to incongruent trials was kept at 1:1. Finally in order to promote the commission of errors to obtain the minimum number of error trials for reliable ERN analysis (Olvet & Hajcak, 2009a), letters making up the stimuli differed across the task (M and N in Block1 and 2, E and F in Block 2 and 4, O and Q in Block 5 and 6, T and I in Block 7 and 8, V and U in Block 9 and 10, and P and R in Block 11 and 12), and stimulus-response mappings were reversed within each block pair (e.g. target M in Block 1 required left button response, whereas in Block 2 target M required a right button response).

Dot probe attentional bias assessment task. The same tennis specific dot-probe task specifically designed for the study conducted in Chapter 4 was employed. The task included the same images of famous tennis players displaying either negative or positive emotions during a tennis game. The dot probe task was designed and presented employing the E-prime software and delivered employing the same equipment employed for the flanker task, described above.

Tennis task. The tennis task employed in this experiment was the same tennis volleying task used in Chapter 3 and 4 with tennis balls being delivered by a ball machine with all settings employed being identical. For this study the tennis task was divided into two blocks of 15 shots (15 forehands and 15 backhands). A set of 10 Dunlop fort tennis balls was employed for the duration of the study and participants used their own rackets.

Measures

EEG recording: Continuous EEG activity was recorded using the BrainVision system (Brain Products, Gilching, Germany) During the Flanker task. Recordings were taken from 32 Ag-AgCl electrodes placed in accordance with the 10/20 system, which comprised of both left and right mastoids. Electro-oculogram (EOG) activity generated by eye movements and blinks was recorded at FP1 and via additional electrodes placed inferior to the right pupil and on the left and right outer canthi (all approximately 1 cm from the pupil). Throughout data acquisition, all electrical signals were digitized at 1024 Hz using the BrainVision recording software (Brain Products, Gilching, Germany). Offline analyses were then subsequently performed using BrainVision Analyzer 2 (Brain Products, Gilching, Germany). Scalp electrode recordings were referenced to the numeric mean of the mastoids and band pass filtered with cut-offs of 0.01 and 30 Hz (12 dB/oct roll off). In addition, ocular artefacts were corrected using the procedure developed by Gratton, Coles, and Donchin (1983). Response-locked data were segmented into individual epochs beginning 200 ms before response onset and continuing for 800 ms following a response. Physiological artefacts were identified using a computer-based algorithm build into BrainVision software and trials in which the following criteria were met were rejected: a voltage step exceeding 50 lV between contiguous sampling points, a voltage difference of more than 200 lV within a trial, or a maximum voltage difference less than 0.5 lV within a trial.

ERN: ERP waveforms were time locked to participant's responses with a 200ms baseline. The ERN was defined as the average activity in the 0–100 ms post response time window at electrode site FCz, where the ERN was maximal. A more negative ERN reflected higher levels of error monitoring.

N2: For the N2 analysis, ERP waveforms were time-locked to target presentation with a 200ms baseline was defined as the average activity in 200 to 300 post stimulus time window at electrode FCz and CZ . N2 Mean amplitudes were calculated on incongruent trials. The N2 was employed for incongruent trials because this type of trial elicit conflict and therefore challenge response inhibition. As with the ERN, a more negative N2 reflects higher levels of conflict monitoring or the application of higher amount of cognitive control.

***Attentional Bias Index (ABI*).** As in Chapter 4, an attentional bias index (ABI) was computed following the methods employed by Notebaert et al. (2015). Reaction times on trials in which the probe replaced the positive image were subtracted from reaction times on trials in which the probe replaced the negative image. A lower ABI score (towards negative) thus reflected a larger attentional bias towards negative images whilst a higher score (towards positive) represented a positive bias.

Quiet eye (QE). As in Chapter 3 and 4 A 'Pupil Lab' head mounted eye tracker (https://pupil-labs.com) was employed to record and measure momentary gaze during the tennis task. As in Chapter 2 and 3 and 4, video data from the mobile eye tracking glasses and external camera were analysed using Quiet Eye Solutions software (www.QuietEyeSolutions.com) employing the procedures highlighted in the methods section of the general introduction. As in previous chapters the QE period for the tennis volleying task was operationally defined as the final tracking gaze on the ball prior to the initiation of the forward swing of the racquet. (see method section of general introduction)

State anxiety. As in previous chapters, cognitive state anxiety was measured using the Mental Readiness Form (MFR-3; Krane 1994) and was assessed at 2 time points during all pre and post tennis tasks (before the first block of 15 shots, midway through the tennis task), and a mean value was used in subsequent analyses.

Tennis performance.

Tennis errors and recovery index (ERI). Performance was evaluated in terms of the percentage of errors made by each participant (i.e. shots missing the target completely). Such 'misses' reflect examples of poor performance and are more likely to occur under competitive pressure (Vine et al., 2013). As in Chapter 4, an error recovery index (ERI) was computed to reflect how players performed following an error. Here we recorded for each participant, the total number of times an error was followed by another error on the volleying task with a lower score reflecting better recovery following a missed shot and a general increased ability to recover from the commission of errors.

Procedure

Lab based session. The experiment was conducted in two single testing sessions. The first testing session was conducted in a sound proof testing booth at Birkbeck college, University of London, UK. Participants were tested individually and gave consent upon arriving at the testing venue. Participants first undertook the dot probe task that started with a brief training block containing 12 trials, followed by the 96 test trials, which lasted for around 6 minutes. Following the completion of these tasks, the EEG cap and sensors were applied (see flanker section for details) and participants undertook a short training version of the flanker task (one block). Participants then completed the flanker task whilst their EEG activity was recorded. Upon completing this lab-based session, all participants were invited to take part in the second session at the Tennis Centre, which involved being tested on the tennis volley task.

Tennis testing session. As in Chapter 4, the tennis session was conducted in a squash court at Coolhurst tennis and Squash club, London, UK. Upon arriving participants were given instructions and undertook a short practice comprising of 5 backhands and 5 forehands to familiarise themselves with the delivery of the ball by the machine. The eye-tracking equipment was then fitted and calibrated using a 6-point calibration procedure. Participants were then asked to complete the MRF-3. During the tennis task participants were required to volley a tennis ball delivered by a ball machine, onto an archery target attached to a blank wall. Participants were instructed to stand with both feet on a designated line whilst keeping a steady ready position, holding their racquet with both hands at around waist height. Upon finishing the first block of 15 volleys, participants were required to complete the MRF-3. Upon the completion of the tennis task participants were then debriefed and thanked for their participation and given a £35 compensation fee for their participation.

As in previous chapters, levels or pressure were manipulated before the tennis volleying task with participants being informed that tennis experts would use the external video data to compare their technique to other participants but also analyze their facial expression during the task, to heighten awareness of the self. Participants were also told that a ranking system based on their performance on the tennis task was in place. Non-contingent feedback was provided, with participants being informed that their level of performance during practice would likely put them in the bottom 30% of the pool of participants already tested. They were in turn told that should their performance stay at this level their data could not be used for the experimenter's PhD study.

Data analysis

Two participants did not complete the tennis task whilst it was not possible to use EEG data from another participant due to technical problems, resulting in a final sample of 32 participants. A set of correlations (see Table 5.1) was conducted between neural indices (i.e. N2 and ERN), Attentional Bias scores and indices of tennis performance (i.e. Tennis Errors and Error Recovery Index). Additionally partial correlations were employed to investigate whether neural indices and performance monitoring such as the N2 and the ERN as well as the QE could explain the relationship between attentional biases and performance on the tennis task as measured by the total number of errors made and in terms of error recovery. Because participants were tested on separate tasks, mediation analyses were not deemed appropriate for the current study. Moreover, for the ERN a repeated measure ANOVA was employed to verify that the ERN was more negative for errors relative to correct responses. Lastly, for the N2 a set of correlations was conducted between the N2 and reaction times to respond on incongruent trials of the flanker task as well as accuracy rates to verify whether the N2 was relating to a slowing of responses.

5.2.3 Results

Manipulation Checks

Cognitive Anxiety - *(MRF-3 Cognitive Anxiety):* Results revealed that during the tennis task performed under pressure, participants reported similar levels of cognitive anxiety (*M* = 3.82, *SD* = 1.62) as reported in the study presented in Chapter 4 where the same pressure induction was employed (*M* = 4.00, *SD* = 1.52) indicating that the pressure manipulation was successful.

Neural indices and performance on flanker task:

ERN (see Figure 5.1). For the ERN a repeated-measures analysis of variance (ANOVA) confirmed that the ERP responses during the flanker task were more negative following errors (*M* = - 2.53, SD = 2.8), relative to correct responses (*M* = .82, *SD* = 3.6), $F(1, 31) = 26.73$, $p < .001$, $\eta p^2 = .46$, confirming that a negative ERN was indeed related to the commission of errors on the flanker tasks.

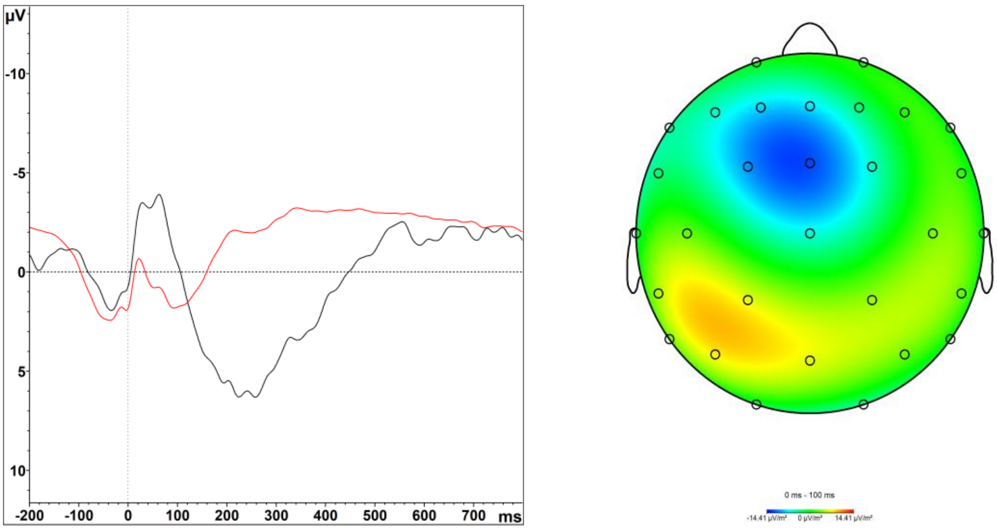


Figure 5.1: *response-locked ERP waveforms recorded from the flankers task at FCz in 32 tennis players (black – Incorrect, Red Correct). On the right Scalp topographies representing the error-related negativity (ERN) derived from the average waveform for error trials.*

N2 (see Figure 5.2). A Pearson's r correlation revealed that the N2 measured on incongruent trials of the flanker task was negatively correlated with RTs on incongruent trials on the Flanker task, $r(31) = -.461$, $p = .009$, $R^2 = .21$

indicating that a more negative N2 was associated with slower RT on incongruent trials (see Figure 1 of the Appendix) . Results did not however reveal a significant correlation between the N2 and Accuracy scores on incongruent trials on the flanker task, $r(31) = -.139$, $p = .44$.

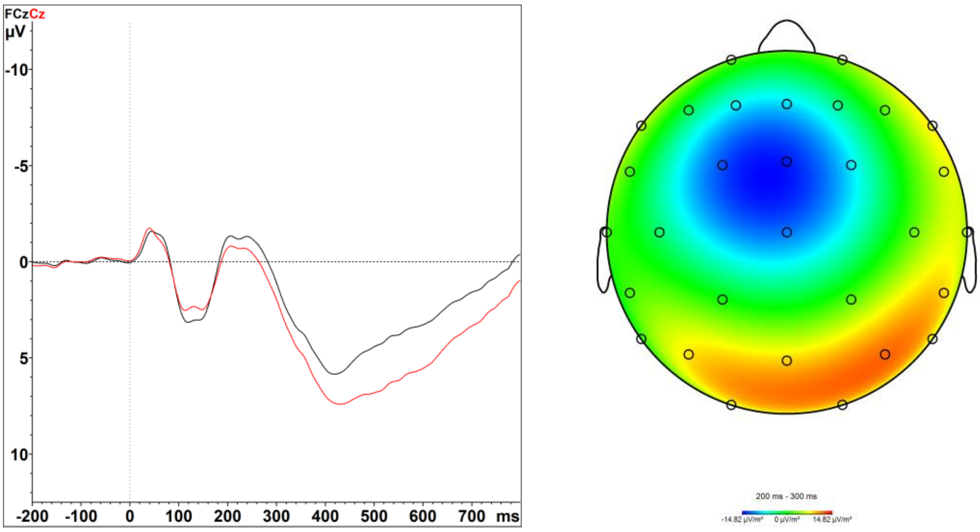


Figure 5.2: Stimulus-locked ERP N2 waveforms recorded from in incongruent trials of flankers task at FCz (black) and Cz (red) electrodes. On the right Scalp topographies representing the N2 derived from the average waveform for incongruent trials.

Correlations: (see Appendix for Scatterplots)

Attentional Bias and Tennis Performance

Attentional bias and Tennis Errors. Results from a Pearson correlation coefficient computed between Attentional Biases Index (ABI) scores and Tennis Errors revealed a significant negative correlation between the two variables, $r(32)$

= -.441, p < .01, R^2 = .17, indicating that participants who displayed more positive attentional bias scores generally made less errors on the tennis task (see Figure 2).

Attentional bias and Error recovery Index. Results revealed a negative correlation between ABI scores and Error Recovery Index (ERI) Scores, r(32) = -.413, p = .01, R^2 = .19, indicating that more Negative Attentional Bias scores were generally associated with a higher Error Recovery ScoreS (i.e. reduced number errors being made following the commission of errors) (see Figure 3)

The N2, Attentional Bias and Tennis Performance

The N2 and attentional Bias. Results revealed a significant positive correlation between the N2 measured on incongruent trial of the flanker task indicating that greater N2 amplitudes (i.e. more negative) were associated with more positive ABI scores r(32) = .378, p =.03, R^2 = .14 (see Figure 4)

The N2 and Tennis Errors. Results revealed a significant negative correlation between the N2 and Tennis Errors rates, indicating that greater N2 (i.e. more negative) were associated with an increase in the number of errors made on the tennis task, r(32) = -.344, p = .05, R^2 = .11 (see Figure 5)

The N2 and Error Recovery Index. Results revealed a significant negative correlation between the N2 measured on incongruent trials of the flanker task and ERI scores, indicating that greater N2 amplitudes (i.e. more negative) were associated with a higher ERI (i.e. reduced number errors being made following the commission of errors), r (32) = -.387, p =.02, R^2 = .14 (See Figure 6)

The QE, Attentional Bias and Tennis Performance

The QE and Attentional Bias Results revealed a significant positive correlation between QE durations and ABI scores that longer QE periods during the tennis task were associated with more positive attentional bias scores $r(32) = .363$, $p = .04$, $R^2 = .13$ (see figure 7)

The QE and Tennis Errors. Results revealed that there was a significant negative correlation between the QE durations and error rates indicating that shorter QE durations were generally associated with increased error rates on the tennis volleying task, $r(32) = -.506$, $p = .003$, $R^2 = .25$ (See Figure 8)

Error recovery and the QE. Results revealed a marginally significant negative correlation between QE durations and the ERI, indicating that shorter QE periods were associated with an increase in the number of errors that were made following the commission of errors on the tennis volleying task, $r(32) = -.327$ $p = .06$, $R^2 = .10$. (see Figure 9)

N2 and the QE. A Pearson coefficient correlation conducted between the N2 and QE did not reveal a significant relationship between the two variables, r $(32) = .183$, $p = .315$. (see Figure 10)

The ERN, Attentional Bias, Tennis Performance and The QE. A series of correlations conducted between attentional bias scores and the ERN did not reveal a significant relationship between the two variables, r $(32) = .14$, $p = .92$.

Additionally, there was no significant relationship between the ERN and Tennis Errors, $r(32) = -.18$, $p = .92$, nor between the ERN and the Error Recovery index, $r(32) = -.235$, $p = .19$. Lastly there was no correlation between the QE and the ERN, r (32) = .000, p =.999.

Table 5.1: *Mean, Standard Deviations and Correlation coefficient values (Pearson r) of model variables.*

	N	*Mean*	*SD*	1	2	3	4	5	6
Attentional Bias	32	-1.028	15.38	1	-.441*	-.413*	.378*	-.014	.363*
Tennis Errors	32	0.264	12.35	-.441*	1	.767**	-.344*	-.018	-.506*
Error recovery	32	1.973	1.82	-.413*	.767**	1	-.387*	-.234	-.327
N2	32	-0.42	3.29	.378*	-.344*	-.387*	1	-.113	.183
ERN	32	-2.543	2.75	-.014	-.018	-.234	-.113	1	0
QE	32	439.36	39.38	.363*	-.506**	-.327	.183	0	1

**p =.05, **p=.01*

Partial Correlations: Attentional bias, tennis performance and attention (QE / N2)

Attentional bias, Tennis error and the N2. Table 5.2 shows results from a partial correlation which was computed between Attentional Bias scores and Tennis Error rates controlling for the N2. Results indicated that when controlling for the N2, the relationship between ABI and Tennis Error scores decreased, $r(32) = -.357$, $p = .05$, $R^2 = .11$, suggesting the involvement of the N2 as measured on incongruent trials of the flanker task in accounting for some of the variance in the relationship between Attentional Bias Index scores and the number of errors made on the tennis task.

Attentional bias, Error recovery and the N2. Table 5.2 shows results from a partial correlation was then computed between Attentional bias scores and scores on the ERI controlling for the N2. Results indicated that when controlling for the N2, the relationship between ABI and ERI scores decreased, $r(32) = - 313$, $p = .08$, $R^2 = .09$, which is suggestive of the involvement of the N2 as measured on the flanker task in accounting for some of the variance in the relationship between Attentional Bias Index scores and the number of errors made on the tennis task following the commission of errors.

Attentional bias, Tennis Error and the QE. Table 5.2 shows results from a partial correlation which was computed between Attentional Bias scores and Tennis Error rates controlling for the QE. Results indicated that when controlling for the QE, the relationship between ABI scores and Tennis Error scores decreased, $r(32) = - 319$, $p = .08$, $R^2 = 10$, which is indicative of the involvement of the QE variable in accounting for some of the variance in the relationship between ABI scores and the number of errors made on the tennis task on the tennis task.

Attentional bias, Error recovery and the QE. A partial correlation was then computed between ABI and the ERI scores controlling for the QE. Results indicated that when controlling for the QE, the relationship between ABI and the ERI scores decreased, r (32) = - 335, $p = .06$, $R^2 = .11$ which is indicative of the involvement of the QE variable in accounting for some of the variance in the relationship between Attentional Bias scores and Error Recovery scores on the tennis task**.**

Table 5.2: *Results from correlations conducted between Attentional Bias Idex scores and Tennis performance measures partialling out for both the N2 and the QE.*

		Tennis Error	**Error Recovery**
Initial coefficient	**Attentional Bias**	*r* = -.441 *p* = .01	*r* = -.413 *p* = .01
Partialling out for N2	**Attentional Bias**	*r* = -.357 *p* = .05	*r* = -.313 *p* = .08
Partialling out for QE	**Attentional Bias**	*r* = -.319 *p* = .08	r = -.335 *p* = .06

5.2.4 Discussion

The first aim of the present study was to verify the findings presented in chapter 4 which related to the implication of attentional biases in predicting performance on a tennis volleying task performed under pressure. Another critical aim of the research was to explore the neurocognitive correlates of error processing, performance monitoring and effortful control employing the ERN and the N2 ERP components measured on a flanker task, to explore whether the involvement of attentional biases in determining tennis performance may be modulated by mechanisms of attentional control. Finally, the present study aimed to verify whether the QE, an objective index of attentional control in sports would be associated with individual differences in attentional biases , performance on a tennis task performed under pressure as well as the N2 and the ERN measured on the flanker task.

Attentional Biases and tennis performance

Results revealed that players' observed levels of attentional biases measured on the dot-probe task, were directly associated with their performance on the tennis task performed under pressure. Indeed, tennis players who displayed a more negative bias were also generally observed to be making more errors on the tennis volleying task. Furthermore, results in turn indicated that participants who displayed a more negative bias were also less able to cope with the commission of errors as they generally more frequently followed up an error with another error. These results further extend the results of the experiment presented in chapter 4, which highlighted the potential impact of attentional biases in determining tennis performance during a tennis task performed under pressure. Indeed, whilst results of chapter 4 indicated that players who had trained to attend away from negative tennis related stimuli (i.e. trained towards a positive bias) tended to perform better on a tennis volleying task than participants who had been trained to attend to negative stimuli (i.e. trained towards a negative bias), the present results revealed a direct relationship between observed levels of attentional biases and tennis performance.

The present results are in line with the original assumptions of ACTS which emphasise the role of attentional biases in modulating the anxiety (pressure)-

performance relationship in sports. Specifically, the present results suggest that when performing under pressure, displaying a negative attentional bias could possibly have led performers to evaluate the potential costs and probability of not performing effectively as being detrimental. As a results this group of performers may have been paying more attention to perceived threat cues during the tennis task. The present results are also in line with the idea that possessing a positive bias and thus not selectively attending to perceived threats should benefit performance by reducing players' perceptions of the costs of making mistakes (Eysenck & Wilson, 2016).

Attentional biases, tennis performance and the N2

A critical aim of the present study was to explore the neurocognitive correlates of error processing, performance monitoring and attentional control using the ERN and the N2 ERP components (measured during performance on a separate flanker task) to assess whether errors and performance monitoring behaviours, as well as the application of effortful control may modulate the relationship between attentional biases and sports performance. Results initially indicated that levels of attentional biases were directly related to the N2 (i.e. effortful control, performance monitoring) measured on incongruent trials of a flanker task. In addition, the N2 was also associated with performance on the flanker task as well as performance on the tennis task which was performed in a separate session. Specifically, results indicated that a more negative N2 on incongruent trials was associated with slower reaction times on the flanker task, confirming that such 'slowing' of responses may reflect the application of effortful control or enhanced attentional control, linked to conflict and performance monitoring (Braver et al., 2001; Jones et al., 2002). Of upmost importance, results in turn revealed that greater levels of negative biases were generally associated with greater N2 amplitudes measured during the flanker task which suggest that individuals who displayed greater negative biases may have resorted to applying higher levels of cognitive effort linked to conflict or performance monitoring when responding to incongruent trials on the flanker task.

Importantly, results in turn revealed that greater N2 amplitudes (i.e. more negative) during the flanker task were also associated with decreased performance on the tennis task (i.e. more errors) as well as a decreased ability to recover from making an error when performing under pressure (i.e. making more errors following the commission of error). These findings strongly suggest that athletes who tended to display a negative attentional bias on the dot-probe assessment task may indeed have resorted to employ compensatory strategies such as applying excessive amounts of cognitive control and engaging in heightened levels of performance monitoring when being confronted with elevated levels of pressure during the live tennis task.

Last but not least, results confirmed that the relationships between levels of attentional biases and indices of tennis performance (error and error recovery) was modulated by the N2 as measured on incongruent trials of the flanker task. Whilst the N2 was not directly measured during the tennis task, these findings do point towards the idea that applying higher levels of effortful control may indeed modulate the relationship between attentional bias and tennis performance. The present results therefore give more insight into the results of chapter 4 and confirm that deficiencies in attentional control could indeed play an important part in explaining the bias-performance relationship in sports as originally theorised by ACTS. Specifically, during the tennis task performed under pressure, displaying a negative attentional bias may have led performers to apply greater amounts of effortful control linked to performance monitoring leading them to potentially consciously focus on movement execution, thus disrupting movement automaticity and eventually leading to impairments in tennis performance (Eysenck & Wilson, 2016). In line with the original predictions of ACTS, participants who showed a more positive bias may have benefited from not engaging in such compensatory strategies which would have led to greater amounts of cognitive resources being available to perform the tennis task. Consequently, this in turn would have resulted in a more flowing and less effortful performance as well a less errors and an enhanced ability to recover from the commission of errors.

Attentional Biases, Tennis performance and ERN:

Whilst it was initially predicted that the occurrence of attentional biases in tennis players may directly relate to the ERN, potentially resulting in increased error processing, results did not reveal any significant relationship between levels of attentional biases and the ERN nor between the ERN and performance on the tennis task or players' ability to recover from the commission of errors. The present results on the ERN cannot verify the suggestion that displaying a negative attentional bias is directly related to error monitoring in anxiety or the idea that ERN may reflect an individual's heightened sensitivity to internal threats such as worries (Weinberger al., 2016). In addition, the present results cannot confirm if the ABM intervention conducted in Chapter 4 would indeed have led participants who trained toward a positive bias to show superior performance on the tennis task by being less likely to engage in behaviours specifically linked to error processing.

Theoretical implications of results relating to the N2 and the ERN

It is important to note that whilst it was initially anticipated that individual differences in levels of attentional biases shown by tennis players would modulate the pressure-performance relationship via its potential impact on both the ERN and the N2, results revealed that the N2 was the sole predictor of this relationship. The present findings on the N2 can be explained using the dual-system model of cognitive control (Botvinick, Braver, Barch, Carter, & Cohen, 2001). Indeed Botvinick et al. (2001) argued that efficient performance tends to rely upon both action monitoring and successful response initiation as well as inhibition, and that cognitive resources tend to be divided between these two distinct functions. Thus, in the current study larger N2 amplitudes measured on incongruent trials of the flanker task may have indeed reflected greater cognitive resources being devoted to action monitoring at the expense of attentional processes (i.e. poorer inhibition). Thus, the N2 may indeed represent a suitable neural marker to assess individual differences in terms of how attentional biases may result in increased performance monitoring (i.e. action monitoring) and effortful control in sports.

Another potential explanation for the lack of results on the ERN may be that this ERP may be less suitable than the N2 when trying to explore performance monitoring behaviours in sports. Indeed, the ERN which peaks around 100ms following a response tends to represent very early processes in terms of conflict monitoring between erroneous and correct responses. Whilst the ERN has been shown to represent a valid index of error monitoring during a simple cognitive task such as the flanker (Moser et al., 2011) which only involves making simple key press responses, hitting a tennis ball delivered at fast pace to a target will require more complex motor and cognitive processing. Consequently, it is very plausible that early processes in error monitoring captured by the ERN may not adequately represent potential conflicts between correct or incorrect motor response occurring during a live tennis task.

Attentional Bias, Tennis Performance and the QE

Last but not least, results indicated that levels of attentional biases were associated with the QE and that the QE was itself directly associated with performance on the tennis task. Specifically, more negative attentional biases were associated with shorter QE durations, which in turn were related to increased errors rates on the tennis task. These results further extend the results presented in Chapter 4 and point towards the idea that the presence of attentional biases in sports performers may impact the anxiety-performance relationship in high pressure sporting contexts via impaired attentional control as measured by the QE. This is also consistent with the original predictions of ACTS. Indeed, ACTS posits that possessing a negative bias should lead sports performers to focus on threat related cues such as worries or external performance related distractors which should result in increased distractibility and therefore promote an internal focus of attention linked to performance monitoring behaviour (egg., an error being a threatening stimulus). As mentioned earlier the potential application of effortful control during the tennis task may have taxed the processing efficiency of participants who displayed negative attentional biases and thus decreased their ability to process information efficiently, resulting in reduced QE duration and decreased performance on the tennis task.

It is however important to note that since the QE was shown to modulate the bias-performance relationship, it would be expected to see QE periods also correlate with the N2, which was also shown to modulate this relationship, and this was not the case. However due to current technical limitation which do not allow to assess ERP's during a live sporting tasks, these different indices of attentional control were obtained in separate tasks which were conducted at different time. In addition, whilst the N2 has been demonstrated to represent a valid index of performance monitoring and cognitive control in lab based cognitive tasks, the role of the QE in supporting performance is more complex. Indeed, long QE durations are associated with both expert-like superior performance (fewer errors) and with task difficulty (more errors) (see Lebeau et al., 2016; Vine et al., 2014). As such, it is difficult to unpick what part of the QE is related to effortful control of task relevant elements, and what part is related to avoiding distractions. As things currently stand, it is likely that a potential relationship between effortful control as measured by the N2 and the QE is not linear but that reduced QE durations could be the direct result of engaging in enhanced performance monitoring behaviours. Indeed, this is in line with the idea that displaying a negative attentional bias could result in performers consciously focusing on movement execution, thus disrupting movement automaticity and therefore leading to choking and substantial impairments in performance (see, Masters & Maxwell, 2008; Oudejans et al 2011).

Whilst the present results are encouraging, this experiment has several limitations which could be addressed by future research. First, the key dependent variables; N2, ERN, levels of biases and QE / sports performance were measured on different tasks, restricting any inference of causality. Future research could therefore attempt to measure neural indices of attentional control before the initiation of a motor movement using resting state EEG during the tennis task to explore whether the commission of errors is indeed related to the application of greater levels of attentional control on tasks that follow an error (see Cooke, Gallicchio, Kavussanu, Willoughby, McIntyre & Ring, 2015). Additionally, future research looking at the impact of attentional biases on the N2 in sports could also measure the N2 during a dot-probe bias assessment task to further explore whether individual differences in attentional biases in sports performers is indeed related to performance monitoring.

Conclusion

In summary, the present results confirm and extend the finding of Chapter 4, revealing that the occurrence of attentional biases in sports may be directly associated with performance under pressure. Indeed, tennis players who displayed a more negative bias also generally made more errors on the volleying task and were in turn less able to cope with the commission of errors. Importantly, the present results present initial evidence for the involvement of attentional control processes in modulating the relationship between levels of attentional biases and performance as well as the ability to recover from the commissions of errors in a sporting task performed under pressure. Specifically results of the present study indicate that when tennis players were required to perform in pressurised sporting contexts, increased effort or increased levels of performance monitoring may have reduced the amount of cognitive resources available to achieve efficient motor preparation and lead to further impairment in attentional control (i.e. shorter QE duration) resulting in decreased performance (i.e. more errors) as well as a reduced ability to recover from the commission of errors. Critically, in line with the recent assumptions of ACTS, effortful control and performance monitoring strategies appears to be directly related to individual differences in levels of attentional biases shown by performers with those who tended to display more negative attentional bias being more likely to engage in such behaviours when faced with elevated levels of pressure. Interestingly, whilst the original assumptions of ACT argue that anxious participants should resort to applying increased levels of attentional control to reach the similar levels of performance as non-anxious individual when undertaking simple cognitive tasks such as the flanker, the present results however suggest that applying excessive amount of effortful control is more likely to be detrimental in sporting contexts where performers often face anxiety provoking situations (see Nieuwenhuys & Oudejans, 2012, 2017).

Chapter 6

General discussion

6.1 General Overview of the Thesis

This thesis set out to explore the neurocognitive mechanisms by which competitive pressure can impact sport performance. In sports, competitive anxiety has been commonly characterised as representing a negative emotional response to stressors (Mellalieu, Hanton, & Fletcher, 2009). Recent research has implicated disruptions to attentional control processes in explaining impaired sporting performance in pressurised sporting contexts (see Wilson, 2012, Eysenck & Wilson 2016). Based on the original assumptions of ACT, sports psychologists have hypothesised that problems related to the top down regulation of goal directed behaviour can result in sports performers displaying heightened levels of distractibility and negative thoughts about performance outcome (i.e. worrying about performance), which can be pronounced under pressurised situations. Consequently, deficiencies in attention control and processing efficiency have been argued to impair sports performers' control of skilled movement execution resulting in deficient motor performance as well as performance outcomes when pressure is elevated (Wilson & Eysenck 2016).

Beside a few studies that have looked at EEG Cortical Alpha Oscillation during sports performance under pressure (Cook et al., 2014; Gallicchio, Cooke & Ring, 2017) research has generally been limited in investigating the neurocognitive underpinnings of performance in motor tasks that involve considerable movements. As such, it has not been possible to fully determine how competitive pressure can negatively impact sports performance, and identify the possible causal role of attentional control as a mediating factor. In an innovative attempt, the studies presented in this PhD used a multifaceted approach using divergent experimental methods from the area of cognitive and affective neuroscience to further elucidate and understand the modulating role of attentional control on performance under pressure. These methods ranged from cognitive training to eye-tracking and EEG methods, validating some of the contemporary interventions in the sports field. The main idea for employing cognitive training methods was that if training related gains could result in benefits on sports performance in pressurised contexts using a training task designed to train specific cognitive mechanisms, it would be possible to infer that such mechanisms can be directly related to athletes' ability to perform at optimal levels in such contexts. Additionally, if training gains were in turn observed on gaze indices believed to represent attentional control in the field (i.e. the QE, FTF), it may also be possible to further establish whether such gaze behaviours which have been widely employed in sports do indeed represent a valid index of attentional control for that specific skill. This has yet to be fully determined by the sports science literature.

The principal purpose of the current PhD thesis was therefore to build upon previous research in cognitive and affective neuroscience and sports science, by marrying theoretical assumptions of ACT (Eysenck et al., 2007) and ACTS (Eysenck & Wilson, 2016) as well as recent developments in cognitive training. Specifically, the thesis explored the impact of pressure related anxiety on attentional control and tennis performance using an integrative, multidisciplinary approach. The aim was to develop and accommodate lab based training interventions, to improve attentional focus and performance in lab-based as well as field-based sporting tasks and to identify and confirm potential neurocognitive mechanisms by which pressure related competitive anxiety may negatively affect sports field performance. Lastly, the thesis investigated whether gaze behaviours such as the QE in sports are indeed directly related to cognitive mechanisms linked with attentional control

6.2 Summary and Discussion of the Main Findings

6.2.1 Inhibition training to improve sports performance

In Chapter 2, a novel visual search training task was employed with the aim of enhancing inhibitory control and tennis performance. In three studies, training transfer effects were explored on an antisaccade task, on a return of serve, a tennis volleying task as well as gaze indices of attentional control in tennis. The set of experiments conducted in Chapter 2 provides initial evidence that training in the lab using a visual search task designed to promote the efficiency of the inhibition function of WM (as well as resistance to distraction) can result in improved cognitive and tennis performance under pressure.

Specifically, in Experiment 1, training on the visual search task led to improved inhibitory control on an untrained anti-saccade task believed to represent a valid index of inhibition. Furthermore, Experiment 2 provided preliminary evidence that training tennis players on the lab based visual search training task, could benefit subjective indices of attentional control in tennis (see Lafont, 2007, 2008). Most importantly, results of Experiment 3 indicated that training inhibitory control using the lab based visual search task, in turn resulted to transfer effects of training on tennis volleying performance and objective gaze indices of attentional control, when participant were required to perform the tennis volleying task under pressure.

Results from the three experiments therefore corroborate and further extend the initial predictions of ACT and ACTS, which emphasise that deficient inhibitory control may be at the root of the problems associated with impaired cognitive and sporting performance when performers are faced with elevated levels of competitive pressure. Importantly, these findings imply that it is possible to train mechanisms related to attentional control in the lab, to enhance tennis performance and gaze indices thought to represent inhibition (i.e. FTF). Last but not least, results of Experiment 3 of Chapter 2 revealed that the ability to inhibit a target fixation around the time of contact with the ball was a significant predictor of performance, emphasising the critical importance of optimal top down control for successful sporting execution under pressure (Englert & Oudejans, 2014; Nieuwenhuys & Oudejans, 2012, 2017). This finding extends previous knowledge in the area of sports which have highlighted the importance of maintaining efficient gaze behaviours during the execution of motor action when undertaking goal directed sporting tasks (Vickers, 1996, Vine et al., 2013).

6.2.2 Working Memory Training

In the experiment presented in Chapter 3, a lab based adaptive working memory training paradigm was employed to investigate whether general gains in working memory capacity and attentional control could transfer to performance improvements during a tennis volleying task performed under pressure. Potential effects of training were also explored on gaze indices believed to represent attentional control in sports (i.e. the QE). Results initially revealed transfer effects of training on an index of working memory capacity. Results in turn revealed that tennis players who undertook training on the adaptive dual n-back WM training task, displayed improved performance on the tennis volleying task performed under pressure. Lastly, results indicated that training led to benefits in terms of gaze behaviours, with trained participants showing enhanced gaze behaviours (i.e. later QE offsets) during a tennis volleying task performed under pressure.

The training related gains observed on working memory capacity are consistent with previous research employing the dual n-back adaptive training paradigm in both healthy and vulnerable populations (Jaeggi et al., 2008; Jaeggi et al., 2011, Owens, et al., 2013, Siegle et al., 2014; Sari et al., 2015; Course-Choi et al., 2017). Additionally, these results also add to the findings of Chapter 2 and provide further evidence that it is possible to train attentional control in the lab to enhance tennis players' ability to counter the costs of performing in pressurised competitive contexts. Furthermore, these findings provided additional support that these training benefits are underpinned by improvements to objective measures of attentional control developed for this tennis volley task.

A secondary aim of the training study conducted in Chapter 3 was to address whether training would transfer to performance on a self-paced dart task which was not within the area of expertise of the tennis players recruited for the study. This was a key extension from Chapter 2, as one potential additional benefit of training generic functions of WM is that training effects might translate to more than one skill (cf. quiet eye training where benefits are task specific). While no transfer of training were found on performance in the dart task, results revealed transfer of training on the QE, with participants allocated to the training group showing longer QE durations in a post- training pressure testing session. These results confirmed that training attentional control process can result in enhancing gaze behaviour such as the QE in an untrained task, highlighting the potential generalisability of this training method. Moreover, these findings are in line with ACT's original predictions which denotes that anxiety tends to impairs processing efficiency to a greater extent than performance effectiveness (i.e. dart throwing accuracy). Findings from Chapter 3 further confirm the idea that the ability to maintain optimal QE duration when performing under pressure is indeed related to the efficiency of working memory processes as well as attentional control (Eysenck & Wilson, 2016, Vines et al. 2014).

In summary, the findings of the set of experiments conducted in Chapter 2 and 3 strongly suggest that elevated levels of anxiety related to the experience of competitive pressure tend to result in performance decrements via deficiencies in attentional control and impairments to the inhibition, switching and updating functions of WM. Additionally these findings in turn confirm that gaze indices such as the QE and FTF may indeed represent a valid measure of attentional control in sports.

6.2.3 The involvement of attentional biases in modulating the pressure-performance relationship.

6.2.3.1 ABM training

Chapters 4 and 5 employed a different approach than Chapters 2 and 3 in that the emphasis was placed on the potential impact of attentional biases as a potential precursor to impairments in attentional control and diminished tennis performance under pressure. This change in emphasis was based partly on an intention to explore recent tenets of ACTS, which placed greater focus on these precursors of attentional disruptions in sport, and additionally because of the opportunity to explore the efficacy of targeted interventions (a key aim of the thesis). Specifically, in chapter 4, a novel sports specific Attention Bias Modification (ABM) training task was employed to explore whether training a sample of experienced tennis players to either attend to tennis related negative or positive stimuli would result in transferrable effects on a dot probe task, as well as performance and the QE during a tennis volleying task under pressure. If anxiety and performance exhibit a bi-directional relationship (as stipulated in ACTS) errors are likely to have a negative valence and hence, are likely to have more effect on participants trained to have a negative bias.

Results revealed the expected differential group effects on post-training bias scores and tennis performance under pressure (both the total number of errors and the likelihood of an error being followed by more errors). As such the findings of Chapter 4 provide initial evidence in support for the idea that impaired inhibition to external and internal threat cues may mediate the anxiety (pressure)-performance relationship (Nieuwenhuys & Oudejans, 2011). These findings are also in line with the recent assumptions of ACTS and confirm the idea that displaying a positive attentional bias will potentially reduce the costs associated with the commission of errors eventually benefiting overall performance, whilst a negative bias will impair sports performers' ability to deal with negative impact of pressure on performance – and errors particularly (Wilson & Eysenck, 2016). However, Chapter 4's results did not confirm whether the training gains observed following ABM training were modulated by cognitive mechanisms directly relating to attentional control, as there was no direct impact on the QE.

6.3.2.2 Attentional Bias, the N2 and performance monitoring

Chapter 5 confirmed that the occurrence of attentional biases in sports may be directly associated with the ability (or the inability) to maintain optimal performance in pressurised contexts. Indeed, results showed that tennis players who displayed a more negative bias were observed to generally make more errors on the tennis volleying task and were in turn less able to cope with the commission of errors. On the other hand a positive bias was associated with efficient performance and an ability to recover from mistakes. Unlike in Chapter 4, results revealed that the attentional bias-performance relationship was also modulated by the QE, supporting the key predictions of ACTS that attentional biases are likely to lead to impaired attentional control under pressure and degraded performance accuracy. As such, these QE results (supported by those from Chapters 2 and 3) give further support for the functional utility of the QE in regulating performance in anxiety provoking situations (Vine et al., 2011, Vine et al., 2014).

Most importantly, in terms of exploring potential neural moderators using EEG ERP indices, it was observed that the association between attentional biases and tennis performance as well as players' ability to recover from the commission of errors was associated with a greater N2, an ERP thought to represent a neural index of effortful control and performance monitoring. Indeed, results indicated that the relationships between participants' levels of attentional biases and indices of tennis performance (errors and error recovery) was modulated by the N2 as measured on incongruent trials of the flanker task. Whilst the N2 was not directly measured during the tennis task, these findings suggested that applying higher levels of effortful control may indeed modulate the relationship between attentional biases and tennis performance. These results therefore confirmed that deficiencies in attentional control could indeed play an important part in explaining the bias-performance relationship in sports.

Additionally , Finding from this EEG based experiment provide further support for the recent assumptions of ACTS, which denotes that effortful control and performance monitoring strategies may be directly related to individual differences in levels of cognitive biases, with sports performers who tend to display negative attentional biases being more likely to engage in such behaviours when faced with elevated levels of pressure. The bi-directional nature of the pressure-performance relationship was also supported as negative biases were related to poorer recovery from performance errors.

6.3 General Implications of the findings

Taken together the findings from this thesis provide initial evidence for the idea that it is possible to train attentional control using lab based cognitive training methods to find transfer of training on both sport performance under pressure and gaze indices believed to represent valid indices of attentional control in sports. These findings are important for the area of sports science as they support the principal assumptions of ACTS, which stipulates that anxiety can result in important deficits in attentional control and subsequent sports performance by reducing the efficiency of the principal functions of WM.

The present findings also hold important implications for the area of cognitive and affective neuroscience that have employed cognitive training interventions. Precisely, they provide further evidence that it may be possible not only to isolate but to also train specific functions of the central executive of WM in order to enhance attentional control and reduce anxiety related distractibility to enable individual to better cope with negative impact of anxiety on cognitive performance (Sari et al., 2016; Course-Choi et al., 2017; Grol et al., 2018). In addition, the present findings in turn indicate that ABM interventions may also be beneficial to athletes performing under pressure and extend previous research in the field of cognitive and affective neuroscience that have shown benefits of ABM interventions in anxious and non-anxious populations (Hayes, Hirsch, and Mathews, 2010; MacLeod & Clark 2015, MacLeod et al., 2002; Eldar et al, 2008).

Furthermore, findings from this thesis in turn have important implications for the area of psychological training in sports. Precisely, it was found that training attentional control in the lab led to enhancements in terms of gaze behaviours such as the QE and FTF in tennis which have been theorised to represent such processes. These findings therefore build on previous research exploring the QE phenomenon and QE training interventions in sports (see Lebeau et al., 2016; Wilson, 2012; Vine et al 2014, Ring et al., 2015). Moreover, these findings also build on other training interventions that have specifically attempted to target neural structures to enhance motor skills and sports performance such as tDCS (Colzato et al., 2016; Zhu et al., (2015) or neurofeedback training (Ring et al., 2014; Zhu et al., 2017).

The present results also provide new lab based training methods to the sports field that could be employed with the aim of equipping athletes with an increased ability to cope with negative impact of pressure related anxiety on attentional control. Previous research in the area of sports science has demonstrated that gaze related attentional strategies could be explicitly taught (Vine et al., 2011; Moore et al., 2012) using instruction to promote efficient gaze behaviours and resilient performance under pressure. However the current research provides initial evidence that similar benefits can be obtained by directly targeting general functions of WM involved in the efficient execution of such actions.

Critically, findings from the present thesis represent the first attempt to investigatie the assumptions of ACTS and the potential neurocognitive mechanisms by which sports performance can be impacted by competitive pressure, by linking results emanating from divergent experimental methods such as EEG and eye-tracking in sports and cognitive training. Specifically, while the first part of the thesis confirmed the involvement of attention control and processing efficiency in modulating performance under pressure, later findings in turn verified the idea initially proposed by ACTS that cognitive biases need to be considered when exploring the impact of competition related pressure on sports performance and attentional control. The current findings are also consistent with ACT's original argument which stipulates that elevated levels of anxiety are associated with individuals employing compensatory strategies such as applying greater levels of effortful control to maintain performance efficiency during simple cognitive goal directed tasks. Nevertheless, it is important to note that in contrast to the original predictions of ACT, the present results importantly suggest that the excessive use of compensatory strategies may be detrimental in sports. Indeed our results indicate that in sports, effort may either be beneficial or detrimental (see Nieuwenhuys & Oudejans, 2011) depending on athletes' propensity to either display negative or positive attentional biases.

The present findings also supplement existing literature exploring the negative impact of pressure on performance in sports and give more insight into the choking phenomenon, which has raised considerable debate in recent times. A large body of research in this area has attributed choking and the inability to maintain optimal levels of performance to the disruptive influence of self-focused attention on the performance of previously learned motor skills (i.e. disrupted automaticity) when pressure is elevated (see Payne, Vine & Wilson, 2018 for a review; Oudejans, et al., 2011; Oudejans et al., 2017 & Buma et al., 2015). Specifically this body of research strongly suggests that increased anxiety and self-consciousness tends to lead performers to turn their attention inward to the skill processes underlying performance (Carver & Scheier, 1978; Lewis & Linder, 1997). Nonetheless, the present findings in contrast, strengthen a distraction account (i.e. ACT) and the recent assumptions of ACTS which stipulate that increased distractibility (e.g. internal worries about performance outcomes) and deficient attentional control resulting from a negative evaluation of a sporting pressure situation, are more likely to results in impaired performance in pressurised sport contexts.

Last but not least, critical gaze behaviours predicted actual performance in the tennis volleying task in all studies presented in the thesis. Whilst the ability to inhibit a fixation to the target when making contact with the ball (i.e. FTF) predicted tennis performance in Experiment 3 of Chapter 3, the QE predicted performance on the tennis volleying task in all experiments presented in Chapter 3, 4 and 5. These findings are in line with previous research on the QE in tennis (Park, 2005; Sáenz-Moncaleano et al., 2018). Furthermore these findings provide further evidence for the functional validity of the QE in promoting efficient motor planning and efficient online control when undertaking a sporting task (Vickers,1996; Klosterman Kredel & Hossner, 2013; Mann et al., 2007) and especially when levels of pressure are high (Vine et al., 2013, Causer et al., 2011). The fact that the different forms of attention control training employed in Chapter 2 and 3 (Visual search and WM training) resulted in improved gazed behaviours, in turn provide further empirical evidence that the QE may indeed be related to attentional control in the sports field. To date, this has only been implied in the literature (e.g. Behan & Wilson, 2008; Causer et al., 2011b; Vickers, 1996; Wilson et al., 2009). As such, this thesis has generated new knowledge to support an attentional role for the QE in supporting performance – especially when attentional demands are high (i.e. under pressure).

6.4 Theoretical model summarizing main findings of the thesis and the potential applicability of cognitive training in pressurised sports contexts.

The results of the series of experiments conducted as part of the thesis can be summarised in a simple model (Figure 6.1) which decomposes different pathways by which the experience of pressure in sporting contexts may lead sports performers to respond differently when experiencing a competitive pressure situation. The model presented in Figure 6.1 confirms the argument raised by ACTS, that competitive pressure will affect sports performers differently depending on their attentional biases.

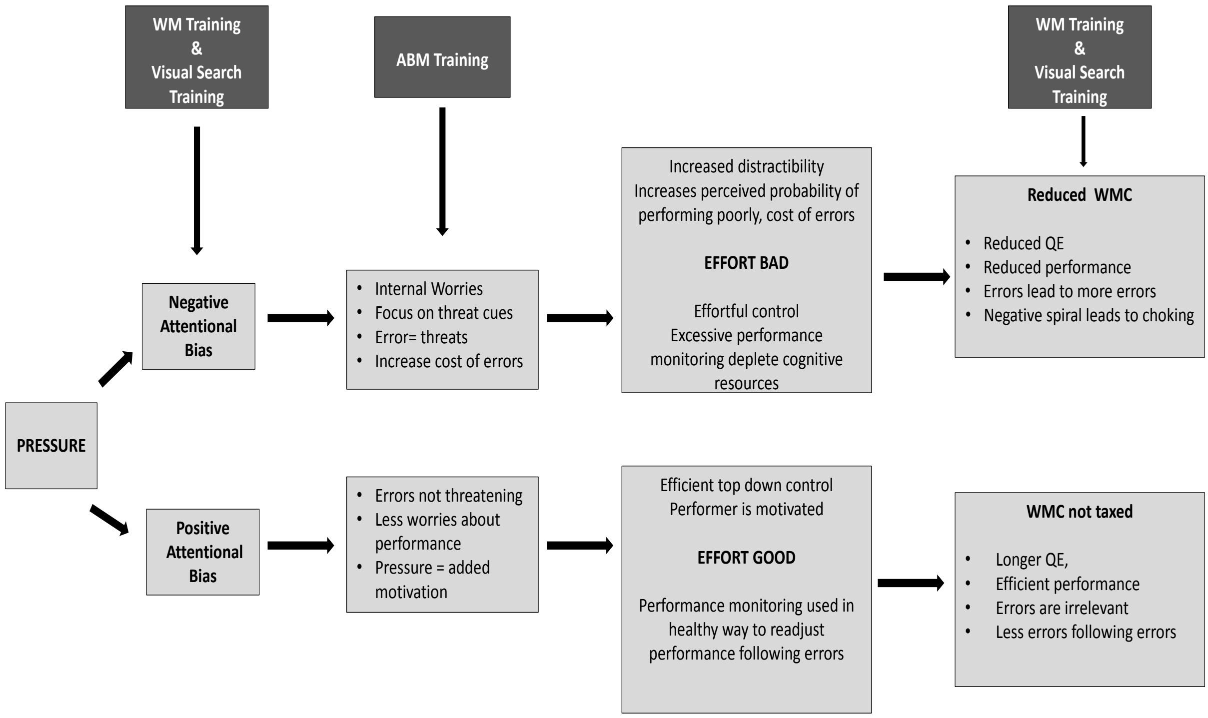


Figure 6.1: *Model showing pathways by which pressure may affect sports performance and applicability of cognitive training interventions in pressurised sports contexts.*

Attentional biases, attentional control and performance

The model indicates that those who tend to display higher levels of negative attentional biases may resort to engaging in exaggerated levels of performance monitoring and effortful control related to worrying about performance outcomes. This behaviour will then result in individuals showing impaired attentional control as well as a reduction in the amount of cognitive resources available to prepare and execute a sporting task goal. Importantly, in this case applying higher levels of cognitive effort to counter the negative impact of pressure will most likely be detrimental to performance. On the other hand the model in turn denotes that athletes who display more positive levels of attentional biases, will respond to the pressure situation by generally becoming more motivated and more focused. In this case possessing a positive attentional bias will lead performers to be less worried about performance outcomes and less distracted by errors which in fact may help athletes adjust their performance and perform more efficiently. It is important to note that as it was initially argued by ACT that differences in original levels of attentional control may also be directly related to performers' propensity to show positive or negative attentional biases and this will be further discussed shortly.

Cognitive training interventions

Importantly, this model also emphasises that the different training methods that were employed in the thesis may help individuals to counter the detrimental impact of competitive pressure on performance in different ways. For example the inhibition training paradigm employed in Chapter 3 may help reduce distractibility to internal threats by enhancing inhibitory control and thus reduce negative biases by enhancing individuals' ability to inhibit threat related stimuli. . Moreover, improving processing efficiency employing WM training could promote top down control and reduced the negative impact of bottom up processes associated with enhanced threat processing, thus also promoting positive attentional biases. This is consistent with recent research by Basanovic et al. (2017) which has shown that changes in bias as a results of ABM training tends to be mediated by individuals differences in attentional control, with those showing higher initial levels of attentional control being more likely to benefit from ABM interventions.

The cognitive training interventions may also promote resilient performance during anxiety and pressure provoking situations by reducing the negative impact of engaging in excessive amounts of effort on attentional control. Specifically, it is highly possible that promoting attentional control and processing efficiency of WM may reduce the taxing impact of engaging in excessive amounts of effortful control on cognitive resources. As shown in Chapter 3, this form of training may indeed promote attentional control processes (i.e. gaze behaviours in sports) and resilient performance under pressure.

Finally, simply employing ABM training to directly target attentional biases at the early stage of the model may alone promote efficient performance under pressure. Indeed the recent assumptions of ACTS suggests that reducing attentional bias to threat may promote the interpretation of a pressure situation as a motivating factor rather than a threatening one, potentially reducing the detrimental impact of competitive pressure on performance.

6.5 Limitations and future research

The model presented above and the potential applicability of the different cognitive training interventions employed in the thesis however raises a number of critical questions relating to individual differences and the relationship between attentional bias, attentional control and processing efficiency of WM. Specifically, would individuals who possess either high or low levels of attentional control be more likely to display positive or negative attentional biases and become more or less resilient under pressure? On the other hand, would sports performers who display either a negative or positive attentional bias in turn show more efficient or impaired attentional control? Such questions may need to be explored to further determine which training intervention may be more appropriate or whether different training methods could be used in conjunction?

Such ideas in turn raise another central question in terms of the theoretical assumptions of ACT and ACTS. Do individual differences in attentional bias always lead to deficiencies in attentional control or do individual difference in attentional control lead to differences in levels of attentional biases displayed by individuals? Another important question also arises in terms of whether negative attentional biases represent a direct cause or a symptom of deficient attentional control. The bigger question being, is it more important to target the cause or the symptom of the problems that are associated with the experience of competitive pressure in sports? Future research in both areas of sports and cognitive and affective neuroscience should aim to disentangle this.

Several questions also remain in terms of individual differences and the potential applicability of the different cognitive training interventions employed in the present thesis. For example if WM is indeed a limited capacity store (Shipstead et al., 2014), then WMC training may not have much utility with individual displaying high levels of WMC, therefore limiting the usefulness of such interventions for this population. If anything, ABM interventions which are believed to be more effective for individuals displaying high levels of attentional control (Basanovic et al., 2017), may be more beneficial with such populations. Results from the present thesis did not provide a specific response to this potential issue and future research in this area should aim to further explore this idea.

The present thesis represents several other potential limitations which could be addressed by further research. First of all, due to the nature of the experimental designs and the time limitations of this PhD research it was not possible to conduct post-training testing sessions at longer time intervals. Indeed, it would have been noteworthy to assess whether the training effects found in the different training studies would be sustainable over time as it was shown in previous research exploring the efficacy of QE training interventions in children with developmental coordination disorder (Miles et al., 2015). Future studies employing cognitive training in sports should therefore aim to further test participants several weeks following an initial period of training. Additionally, whilst beneficial transfers of training were observed on a simple tennis volleying task future research could further explore whether training would transfer to performance during a live tennis match. For example future research could explore how training would affect players ability to cope with big pressure point. Future research could also explore whether training benefits would in turn relate to general performance in tennis in terms of games or sets won over a prolonged period of time.

Another potential limitation of the body of research presented in the thesis revolve around the nature of the tennis sample involved in this study. Whist the experiment conducted in Chapter 2 employed recreational tennis players who engage in tennis activity at least once per week, tennis players who regularly engage in club competitive activities were recruited for the remaining studies. Nevertheless research in sports as shown that experts across a wide array of sporting disciplines generally show higher levels of attentional control as measured by the QE (Vickers 1996; Mann et al., 2007). Moreover, previous research in sports has shown that experts can also be sensitive to the impact of competitive pressure

(Wilson, 2012). Consequently the present thesis cannot at this stage draw clear conclusions about the potential benefits that cognitive training may elicits in elite tennis players or expert sports performers. Moreover, it is also difficult to draw firm conclusions in terms of the impact of cognitive biases in elite sports. Future research looking at the impact of competitive pressure on sports performance should aim to investigate the principal findings of the thesis in expert tennis players to further investigate the assumptions of ACTS.

Lastly, whilst the present findings provide encouraging initial evidence for one of the principal assumption of ACTS which emphasises efficient attentional control as being a strong predictor of successful performance under pressure, more research is needed to further explore ACTS' original predictions which highlight the bidirectional relationship between anxiety and performance. For example, future research should aim to further explore how state anxiety may modulate how the commission of errors during a sporting task can impact attentional control (i.e. the QE) and performance on a subsequent attempts. Whilst the research presented in this PhD indicated that tennis players displaying a positive bias were less likely to make an error following an error, we did not specifically measure state anxiety before each attempt on the tennis task. Future research could also explore how elevated levels of state anxiety following an error, may directly influence performers' perception of the potential costs associated with the commission of errors as well as the perceived probability of performing poorly.

Finally, whilst the present findings highlight the role of attentional biases in modulating sports performance under pressure, ACTS also strongly emphasises that such biases will also impact how performers will interpret a pressure situation. Future research could specifically explore the potential role of interpretational biases in affecting performance monitoring behaviours and modulating the anxiety-performance relationship as a whole but also following every attempts during a sporting task.

6.6 Concluding Comments

Taken together, the findings presented in the present thesis provide initial evidence that it is possible to train attentional control in the lab to show beneficial effects on tennis field performance in pressurised contexts. The current findings also provide novel insight into the potential neurocognitive mechanisms that modulate how sports performers respond to competitive pressure. Specifically, these findings confirm the commanding role of attentional control and attentional biases in modulating the impact of competitive pressure on sports performance. Moreover, the present findings further suggest that gaze indices such as the QE may indeed relate to attentional control processes in sports. Finally, findings from the thesis not only hold important theoretical and practical implications in the area of sports but may also be applicable to other domains where the experience of pressure is highly prevalent. Precisely, the practical significance of the findings could be targeted towards to non-sporting domains such as surgery, aviation, or the military where individuals are often required to perform complex and fine motor movements under extreme levels of pressure.

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APPENDIX

Scatterplots for correlations analyses presented in experiments 5.

N2 and RTs on incongruent trials of flanker task

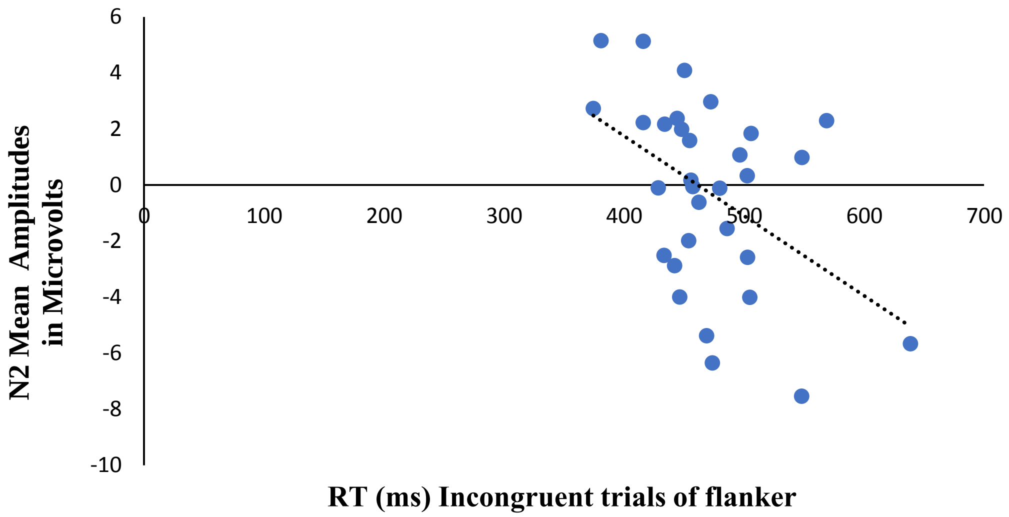

Figure 1: *Correlation between the N2 and reaction times on incongruent trials of the flanker task.*

Attentional Biases and Tennis Performance

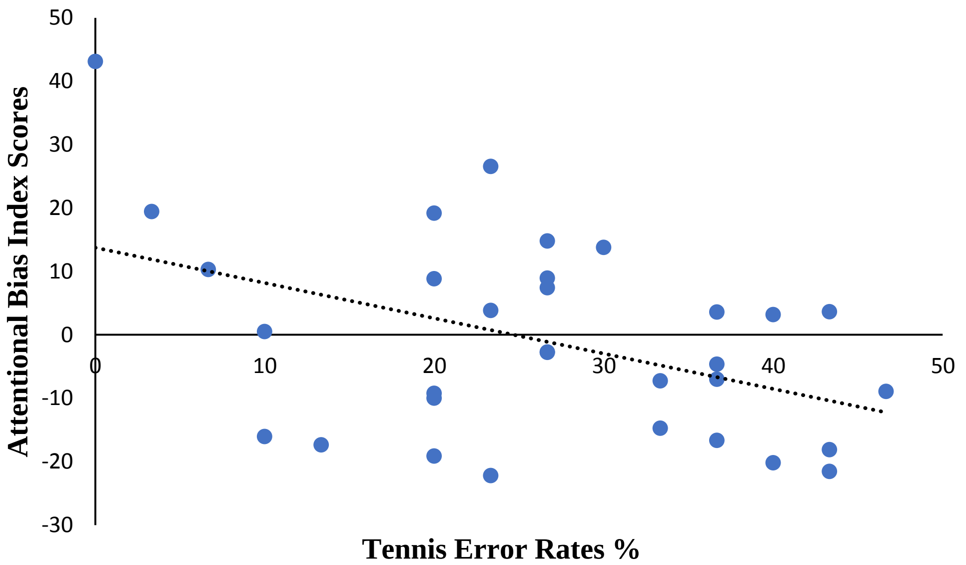

Figure 2: *Correlation between Attentional Bias Index scores and Tennis Error Rates*

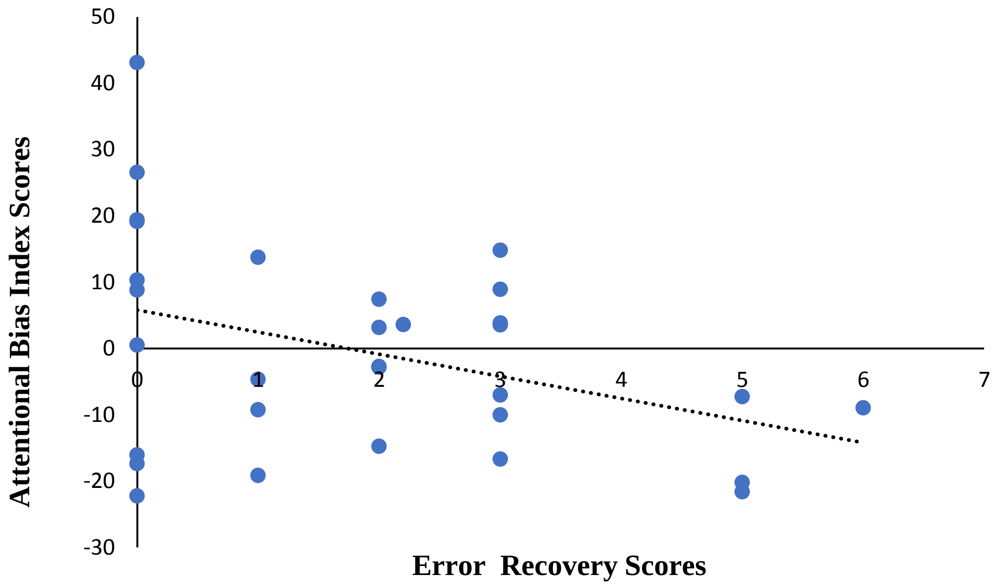

Figure 3: Correlation between Attentional Bias Index scores and Tennis Error Recovery scores

The N2, Attentional Bias and Tennis Performance

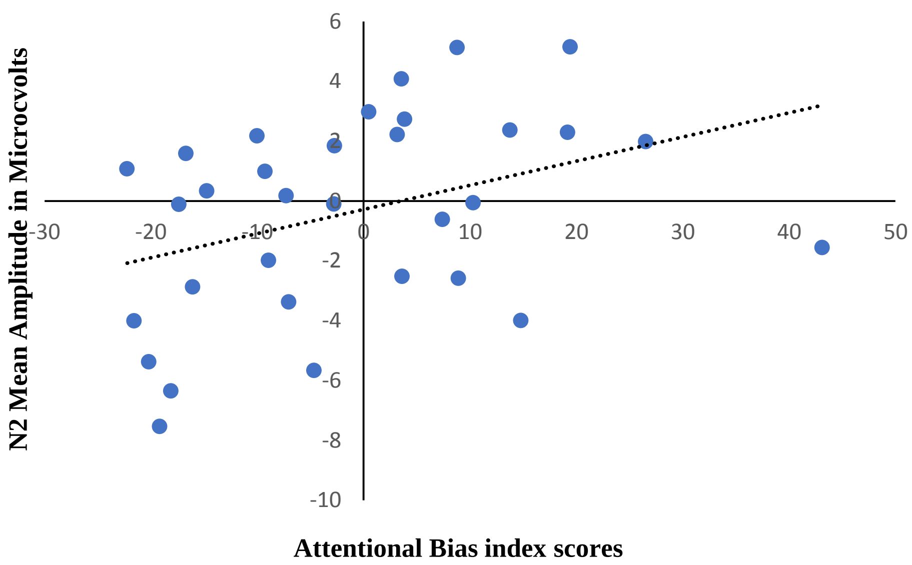

Figure 4: Correlation between the N2 and Attentional Bias Index scores

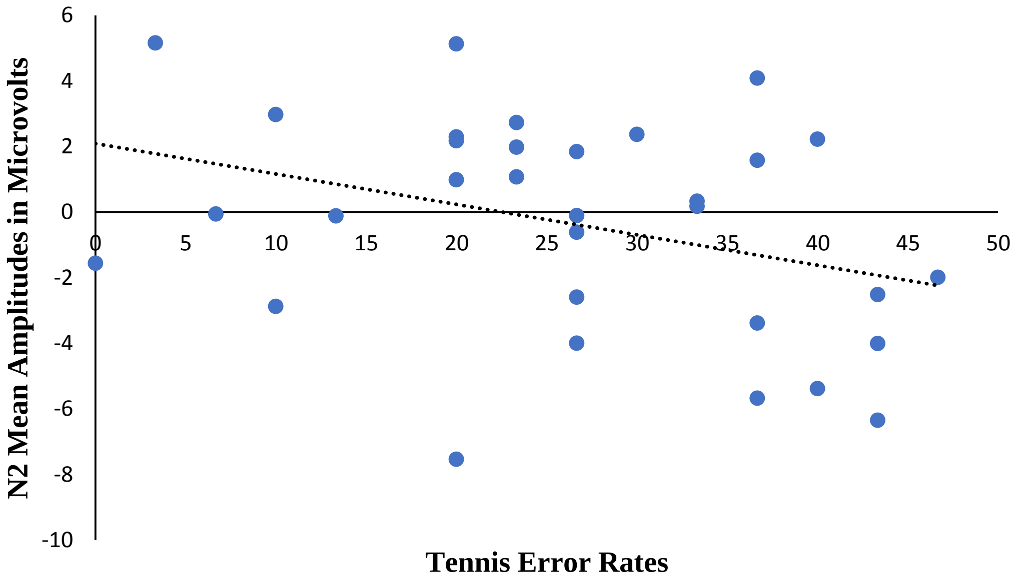

Figure 5: *Correlation between the N2 and tennis Error Rates.*

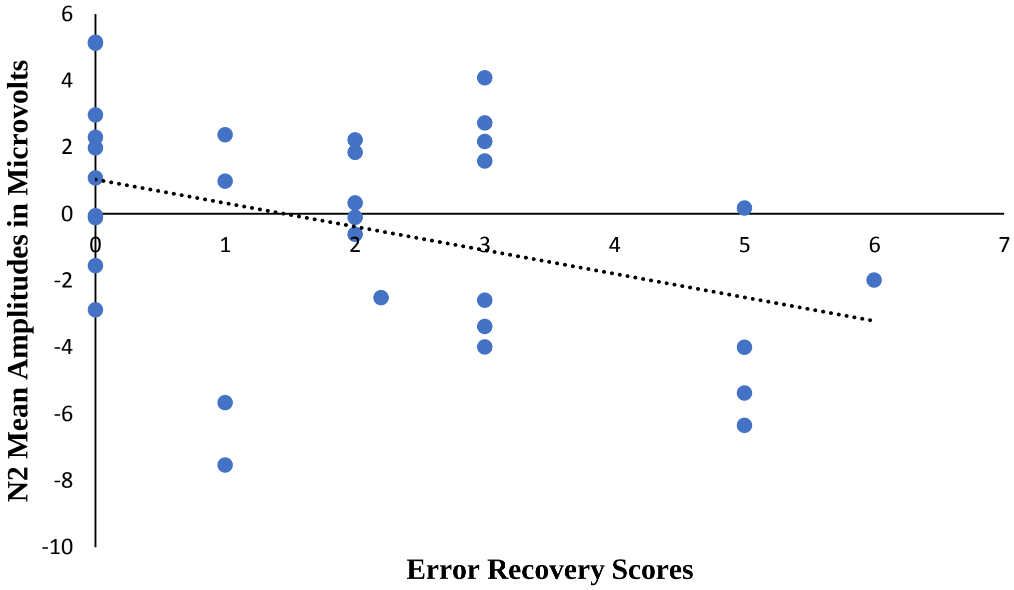

Figure 6: *Correlation between N2 and tennis error recovery scores.*

The QE, Attentional Bias and Tennis performance

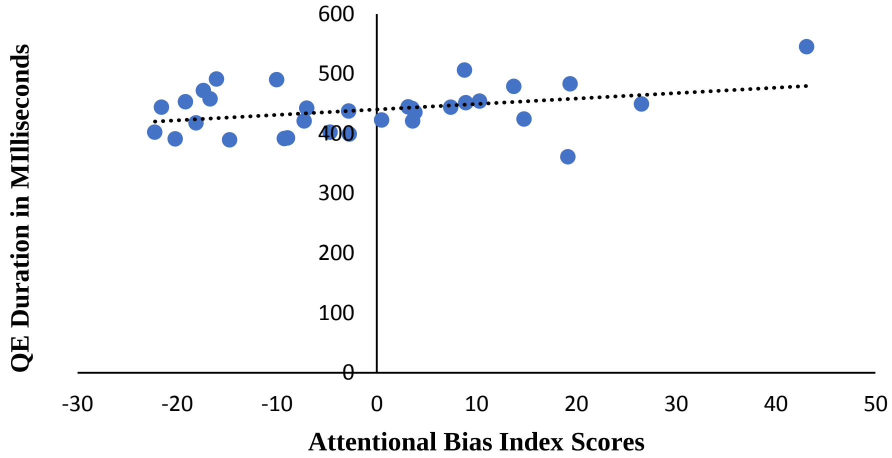

Figure 7: *Correlation between QE durations and Attentional Bias Index scores*

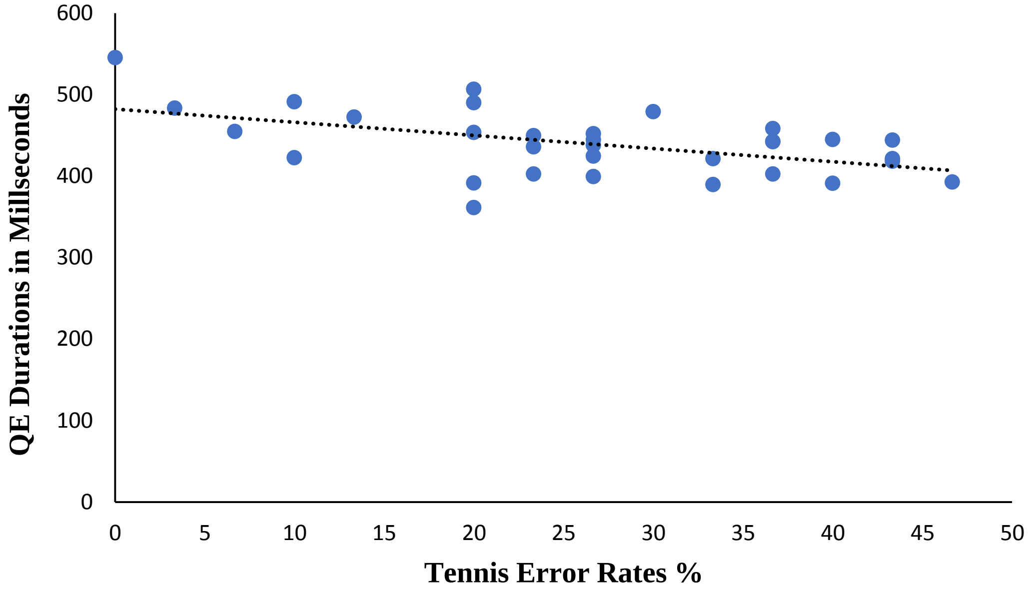

Figure 8: *Correlation between QE Durations and Tennis Error Rates.*

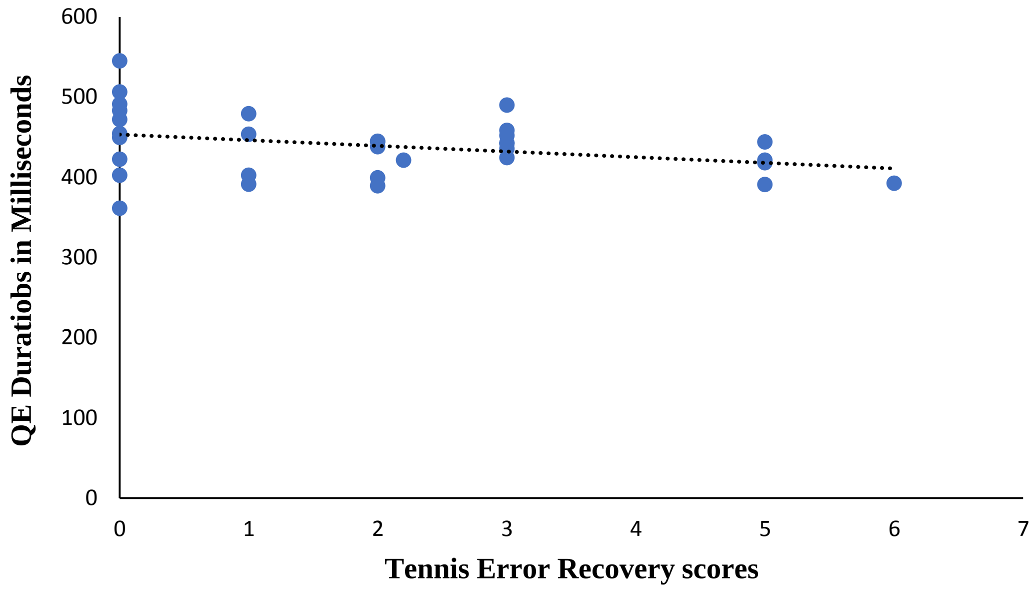

Figure 9: *Correlation between QE Durations and Tennis Error Recovery Scores.*

N2, Flanker RTs, Tennis Performance and Attentional Bias

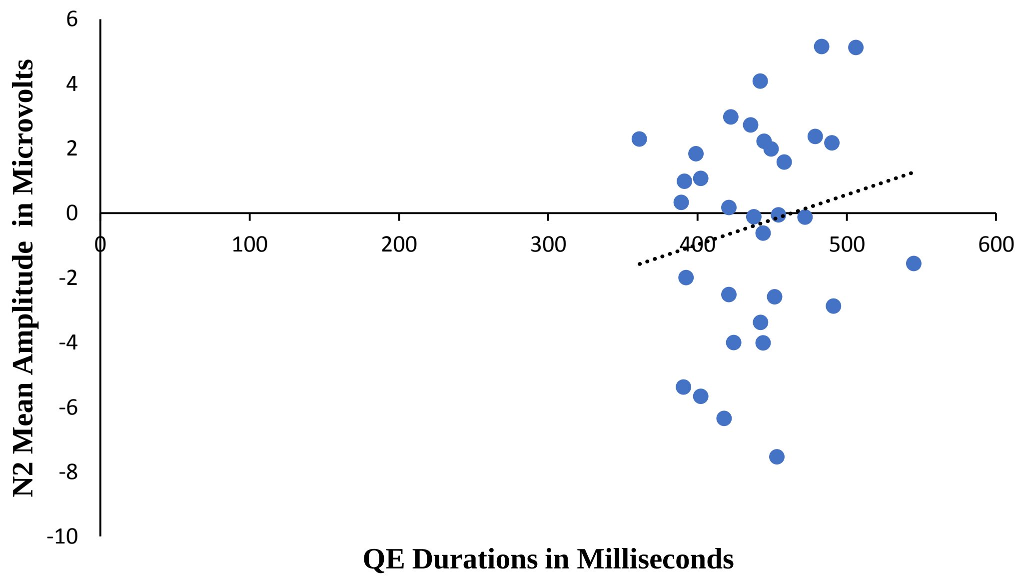

Figure 10: *Non significant correlation between the N2 and the QE*